Appendix G
Aquifer Testing

APPENDIX G – AQUIFER TESTING

LIST OF FIGURES

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1.0   *INTRODUCTION*

In situ aquifer tests and constant-rate pumping aquifer tests were conducted at the Hookston Station Parcel and downgradient study area to support remedial alternative evaluations for the Feasibility Study. This appendix describes the field activities conducted, documents the field and analytical methods used, and presents the results of the aquifer tests.

The aquifer testing was performed in order to evaluate the hydraulic responses and properties of the A-Zone and B-Zone aquifers to pumping stresses, including aquifer transmissivity, hydraulic conductivity, and storativity.

2.0   SCOPE OF WORK

In situ aquifer tests and constant-rate pumping tests were conducted at the Hookston Station Parcel and downgradient study area during 4 to 12 April 2006. In situ aquifer tests were performed at 11 monitoring wells (MW-5, -7, -8B, -14A/B, -15A/B, -16A/B, and -17A/B). A constant-rate pump test was conducted in A-Zone well MW-5, and a constant-rate pump test was conducted in a new B-Zone well, TW-1. Well locations are included on Figure G-1.

The following sections describe the field activities and methods that were completed for these tasks.

2.1   PRE-AQUIFER TEST ACTIVITIES

Activities completed prior to the completion of the aquifer tests included the installation and development of a B-Zone pumping well, TW-1. Prior to installing the well, the following activities were completed:

- A well installation permit was obtained from the Contra Costa County Environmental Health Department;

- Underground Service Alert was notified at least 48 hours prior to the commencement of drilling activities; and

- ForeSite Engineering Services, a private utility locating service, was retained to clear the drilling location.

Gregg Drilling and Testing, Inc., a drilling subcontractor from Martinez, California, was retained to perform the well installation. A hollow-stem auger drill rig was used to conduct the drilling, sampling, and well installation activities on 5 to 6 April 2006. The drilling location was hand-cleared to 5 feet below ground surface (bgs) to minimize the potential for encountering underground utilities during drilling activities. The boring was then advanced to 75 feet bgs with 6-inch diameter hollow stem augers. Soil samples were collected continuously using 18- and 24-inch California-modified split spoon samplers. Boring logs were prepared in the field by an ERM-West, Inc., geologist using the Unified Soil Classification System to describe soils. The geologist recorded vertical changes in soil lithology, color, moisture content, grain size, and texture, as well as any observations of staining or odors.

Soil samples were collected for geotechnical analysis from the unsaturated zone, the A-Zone aquifer, the B-Zone aquifer, and the clay units between the A-, B-, and C-Zones (6.5, 10, 30, 39.5, 46.5, and 75 feet bgs). The samples were collected in shelby tubes or brass liners that were driven with split spoon samplers. Samples were labeled and sent under proper chain-of-custody procedure to Cooper Testing Labs in Palo Alto, California, for the following analysis:

- Grain size distribution (American Society for Testing and Materials [ASTM] D422);

- Dry bulk density, total porosity, effective porosity, air-filled porosity, water-filled porosity, and moisture content (API RP40 and ASTM D2325m);

- Specific gravity (ASTM D854m);

- Percent saturation and hydraulic conductivity (ASTM D5084); and

- Total organic content (Walkley-Black).

The results of the geotechnical testing are provided in Appendix F of the Feasibility Study/Remedial Action Plan.

Once the total depth of the boring was reached and samples were collected, the boring was then over-drilled with 10-inch diameter hollow stem augers in order to accommodate the installation of the well materials. TW-1 was then constructed with 4-inch diameter polyvinyl chloride screen (0.020-inch machine-slotted) from 45 to 75 feet bgs and blank riser pipe to the ground surface. A filter pack of #3 sand was emplaced within the annular space to approximately 3 feet above the top of the screen interval. The transition seal consisted of 3 feet of bentonite chips hydrated with potable water approximately 30 minutes prior to placement of the cement-bentonite seal. TW-1 was completed at the ground surface with a flush-mounted well vault, watertight expansion cap, and secured with a lock.

TW-1 was developed on 8 April 2006 using air-lift techniques. Approximately 600 gallons (roughly 15 well volumes) were removed from the well. The well was also surged during development to remove any sediment that may have entered during installation. Stabilization parameters (pH, specific conductance, turbidity, and temperature) were monitored and recorded during development.

Copies of the well logs are provided as Attachment A.

2.2   AQUIFER TESTING

Activities conducted during the aquifer tests are summarized in the following sub-sections.

2.2.1   Background Monitoring

Well hydraulics equations used in aquifer test analyses assume static, steady-state initial conditions, wherein water levels are constant in time and space prior to pumping. Before aquifer test data can be analyzed, they must be adjusted for any significant, extraneous water-level fluctuations. Therefore, water level data were collected prior to conducting aquifer tests.

Pre-aquifer test water level data were collected from each of the wells that were utilized during the constant-rate pumping tests (observation wells and pumping wells). Background water level data were also collected from two additional wells (MW-23A/B) prior to and during the pump tests. In addition, a barometric pressure transducer was programmed to take readings of barometric pressure every 10 minutes throughout completion of the aquifer testing.

The water levels were monitored continuously with dataloggers and pressure transducers for a minimum of 2 days prior to the constant-rate pumping tests. These data were evaluated for possible use in correcting the aquifer test data for changes in atmospheric pressure or local uncontrolled aquifer stresses.

2.2.2   In Situ Aquifer Testing

In situ aquifer (slug) tests were performed on 4 and 5 April 2006 in six A-Zone wells (MW-5, -7, -14A, -15A, -16A, and -17A) and five B-Zone wells (MW-8B, -14B, -15B, -16B and -17B). The slug tests were conducted in accordance with the standard operating procedure (SOP) for In Situ Aquifer Tests (Attachment B).

The following procedures were followed for the set-up and completion of each slug test.

Prior to conducting the slug test, the depth to water was measured with an electronic sounder and recorded in the field notebook. A pressure transducer was then installed in the well. The transducer was installed at such a depth that the addition and removal of the slug would not interfere with the transducer and that the water level would not fall below the

transducer. The transducer was then secured at the top of the well using a stainless steal hanger. The transducer was then programmed such that the reference value was equal to zero and that readings would be collected every second during the slug test.

A rising-head slug test was performed at each well. Following installation of the pressure transducer and initiation of readings, the slug was gently lowered into the well below static water level. The water level was then monitored until it recovered to static conditions. Following confirmation that the slug was completely submerged within the water column and static water levels were restored, the slug was instantaneously removed from the well. One bailer (1.6-inch diameter by 3 feet) was used in the A-Zone slug tests and two bailers (each 1.6-inch diameter by 3 feet) were used in the B-Zone slug tests. After the slug was removed, the pressure transducer recorded data until the water level stabilized. A laptop computer was used to determine when stabilization had been achieved. In addition, manual water level measurements were recorded during the test. Once the water level had stabilized, the pressure transducer was stopped and a final manual water level measurement was collected and recorded in the field notebook.

2.2.3   *Step-Drawdown Tests*

A step-drawdown test is a single-well test in which the well is pumped at a constant rate until drawdown in the well has stabilized. The pumping rate is then increased to another constant rate until the drawdown has stabilized again. Step-drawdown tests usually consist of at least three different, constant-rate discharge steps. Data collected from these tests may be used to determine the sustainable yield of a well.

Prior to the constant-rate pump tests, a step-drawdown test was performed in each of the wells that were to be used as the "pumping" well for each test (MW-5 and TW-1). These step-drawdown tests were performed to determine the optimal flow rate for each of the constant-rate pumping test. A pressure transducer was installed in the pumping well prior to the start of the step-drawdown test. Water levels were also measured manually with an electric sounder to verify depths measured using the transducer.

During the A-Zone step-drawdown test, MW-5 was pumped at four different rates. The discharge rates used were 1, 3, 4, and 5 gallons per minute (gpm). During the B-Zone step-drawdown test, TW-1 was pumped at four different rates. The discharge rates used were 5, 10, 15, and 18 gpm. Each pumping rate was maintained until drawdown

approximately stabilized. During the test, a plot of drawdown versus elapsed time was created to determine the duration of each pumping rate and estimate the rate increase for the next step.

Discharge rates were measured using an in-line flowmeter to monitor the flow rate and total gallons pumped. The flowmeter was checked periodically by measuring the time it took to fill a 5-gallon bucket. Groundwater extracted during the step-drawdown tests was stored at the Hookston Station Parcel in Baker Tanks pending waste characterization and proper disposal.

2.2.4   *A-Zone Constant-Rate Pump Test*

The A-Zone constant-rate pump test was performed on 10 April 2006. Monitoring well MW-5 was utilized as the pumping well and MW-8A, -11A, -13A, -15A, and -20A were utilized as observation wells. In addition, water levels were monitored in B-Zone observation wells MW-8B, -11B, -13B, -15B, and -20B to record possible influence to the B-Zone as a result of A-Zone pumping. All pump test procedures were completed in accordance with the SOP for Aquifer Pump Tests, included as Attachment C.

The constant-rate pumping rate was determined based on the step-drawdown test data, and a target pumping rate of 4 gpm was chosen. Prior to starting the pumping test, a round of manual water levels was collected from the observation wells and transducers were programmed to begin collecting data on a log scale.

Pumping began at 8:30 a.m. on 10 April 2006. Water levels were measured at logarithmic time intervals in the pumping well and observation wells with dataloggers and pressure transducers at least as frequently as follows:

Elapsed Time (Minutes)	Frequency of Measurement
0 – 10	1 second
10 – 30	1 minute
30 - 60	2 minutes
> 60	5 minutes

Each of the transducers was vented to the atmosphere to minimize interference from barometric pressure changes. Manual water levels were also measured periodically during the tests.

A constant yield of approximately 4 gpm was maintained throughout the test; if the rate deviated by more than 5 percent, the discharge valve was adjusted. The test duration was determined based on the drawdown observed over time in the pumping well and observation wells. Due to the drawdown observed in MW-5 and the surrounding observation wells, the test was stopped at 6:30 p.m. on 10 April 2006. Therefore, the A-Zone constant-rate pumping test was run for a total of 10 hours.

Recovery of water levels in MW-5 and the observation wells was monitored immediately upon cessation of pumping. Measurement frequency was similar to that of the measurements taken during the pumping portion of the test, as described above. The duration of the recovery test was approximately 20 hours.

2.2.5   *B-Zone Constant-Rate Pumping Test*

The B-Zone constant-rate pump test was performed on 12 April 2006. Test well TW-1 was utilized as the pumping well while MW-8B, -11B, -13B, -15B, and -20B were utilized as observation wells. In addition, water levels were monitored in A-Zone observation wells MW-8A, -11A, -13A, -15A, and -20A to record possible influence to the A-Zone as a result of B-Zone pumping. All pump test procedures were completed in accordance with the SOP for Aquifer Pump Tests, included as Attachment C.

A target pumping rate of 25 gpm was chosen, based upon the results of the step-drawdown test and the storage capacity for discharge water. Prior to starting the pumping test, a round of manual water levels was collected from the pumping well and observation wells and transducers were programmed to begin collecting data on a log scale.

Pumping began at 8:30 a.m. on 12 April 2006. Water levels were measured at a logarithmic time interval in the pumping well and observation wells with dataloggers and pressure transducers at the same scale discussed above for the A-Zone test (Section 2.2.4). Each of the transducers was vented to the atmosphere to minimize interference from barometric pressure changes. Manual water levels were also measured periodically.

A constant yield of approximately 25 gpm was maintained throughout the test; if the rate deviated by more than 5 percent, the discharge valve was adjusted. The test duration was determined based on the drawdown observed over time in the pumping well and observation wells. Due to the drawdown seen in TW-1 and the surrounding observation wells, the test was shut down at 4:30 p.m. on 12 April 2006. The B-Zone constant-rate pumping test was run for a total duration of 8 hours.

Recovery of water levels in TW-1 and the observation wells was monitored immediately upon cessation of pumping. Measurement frequency was similar to that of the measurements taken during the pumping portion of the test, as described above. The duration of the recovery test was approximately 16 hours.

3.0   RESULTS

The results of the aquifer test analyses are described in this section. The analytical methods and assumptions used for the analyses are also documented below.

3.1   AQUIFER TEST ANALYTICAL METHODS AND ASSUMPTIONS

The data set collected during the aquifer tests includes manual and datalogger data from 21 wells, representing both the A-Zone and B-Zone aquifers. This includes data collected during background, slug tests, step-drawdown tests, constant-rate pumping tests, and recovery tests. The aquifer test data were analyzed with the assistance of aquifer testing analysis software (Waterloo Hydrogeologic, Inc., 2002, and HydroSOLVE, Inc., 2002) to facilitate consistent analysis. Aquifer test time-drawdown and distance-drawdown analyses are provided in Attachment D.

The following analytical methods were used to analyze the aquifer test data:

- Bouwer-Rice Slug Test Method, 1976;

- Cooper-Jacob Time Drawdown Method, 1946 (confined);

- Cooper-Jacob Distance-Drawdown Method, 1946 (confined);

- Papadopulos-Cooper Single Well Method, 1967;

- Theis Method, 1935 (confined); and

- Theis Recovery Method, 1935.

Some notable assumptions include the following:

- The selected analytical methods reflect confined conditions, consistent with the geologic model and data for the Hookston Station Parcel;

- A 16-foot saturated thickness was applied to the A-Zone constant-rate pumping test analysis (based on the sand aquifer thickness at MW-5). This saturated thickness was also applied to the analyses of the A-Zone observation wells for consistency; and

- A 30-foot saturated thickness was applied to the B-Zone constant-rate pumping test analysis (based on the sand aquifer thickness at TW-1).

A 30-foot saturated thickness was also applied to the analyses of the B-Zone observation wells in order to maintain consistency.

3.2   A-ZONE AQUIFER TEST RESULTS

The results of the A-Zone aquifer test analyses are summarized below and on Table G-1.

The following A-Zone aquifer characteristics were calculated from the A-Zone slug test data:

- Average transmissivity (T) = 3.1 centimeters squared per second (cm^2/s), or 284 feet squared per day (ft^2/day).

- Average hydraulic conductivity (K) = $6.54x10^{-3}$ centimeters per second (cm/s), 19 feet per day (ft/day).

During the A-Zone constant-rate pump test, no drawdown was measured in the observation wells; therefore, the data obtained from the pumping well was analyzed using a single well test solution (Papadopulos-Cooper, 1967). For the A-Zone aquifer, the following aquifer characteristics were calculated from the MW-5 constant-rate pumping test:

- T = 0.59 cm^2/s (56 ft^2/day).

- K = $1.21x10^{-3}$ cm/s (3.4 ft/day).

These results are consistent with published values of K for silty sands and fine sands (Fetter, 1994). Water levels collected in A-Zone observation wells during the B-Zone pump test were analyzed to determine what, if any, connection exists between the two aquifers. Analysis of the water levels collected in B-Zone observation wells during the A-Zone pump test indicates that there was no influence observed in the B-Zone aquifer that is attributable to the A-Zone pumping.

3.4   B-ZONE AQUIFER TEST RESULTS

The results of the B-Zone aquifer tests are summarized below and on Table G-2.

The following transmissivity and hydraulic conductivity values were calculated from the results of the B-Zone slug tests:

- Average T value of 1.4 cm^2/day (132 ft^2/day).

- Average K value of 5.23×10^{-3} cm/s (15 ft/day).

The following transmissivity and hydraulic conductivity values were calculated from the results of the B-Zone constant-rate test:

- Average T value of 14 cm²/s ($1.32 \times 10^{+3}$ ft²/day).

- Average K value of 1.89×10^{-2} cm/s (54 ft/day).

These results are consistent with published values of K for a well-sorted sand (Fetter, 1994). Water levels collected in A-Zone observation wells during the B-Zone pump test were analyzed to determine what, if any, connection exists between the two aquifers. Approximately 3 feet of drawdown was observed in MW-13A, located within 10 feet of TW-1. None of the other A-Zone observation wells showed measurable influence as a result of B-Zone pumping. These results suggest that the A-Zone and B-Zone aquifers are to some extent connected, however localized in nature.

4.0   REFERENCES

Bouwer, H. and R.C. Rice. 1976. *A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells.* Water Resources Res. Vol. 12, pp.423-428.

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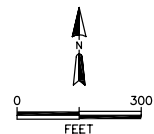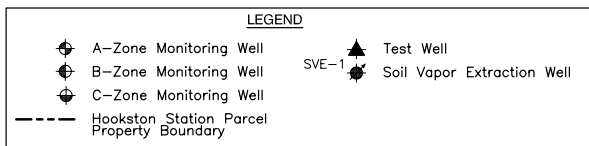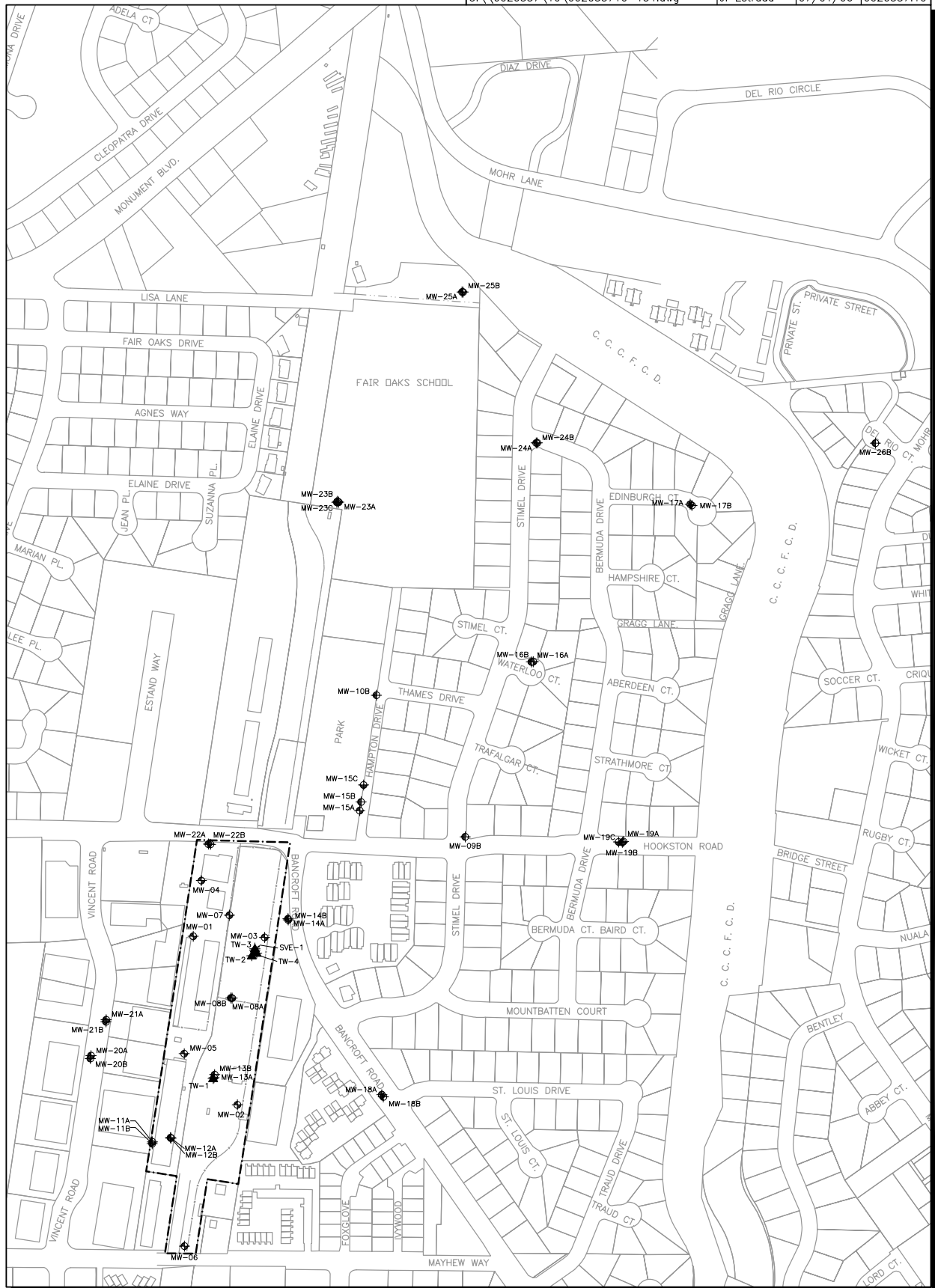Waterloo Hydrogeologic, Inc., and Thomas Rhorich. 2002. *Aquifer Test v.3.5.*

Figures

ADELA CT.

CLEOPATRA DRIVE

MONUMENT BLVD.

DIAZ DRIVE

DEL RIO CIRCLE

MOHR LANE

LISA LANE

FAIR OAKS DRIVE

AGNES WAY

ELAINE DRIVE

ELAINE DRIVE

FAIR OAKS SCHOOL

PRIVATE ST.
PRIVATE STREET

C. C. C. F. C. D.

MW-25B
MW-25A

JEAN PL.

SUZANNA PL.

MARIAN PL.

MW-23B
MW-23C MW-23A

MW-24B
MW-24A

DEL RIO CT.
MW-26B

STIMEL DRIVE

BERMUDA DRIVE

Edinburgh CT.
MW-17A MW-17B

GRAGG LANE

C. C. C. F. C. D.

LEE PL.

ESTAND WAY

HAMPSHIRE CT.

STIMEL CT.

WATERLOO CT.

MW-16B MW-16A

WHIT

PARK

HAMPTON DRIVE

THAMES DRIVE

MW-10B

ABERDEEN CT.

SOCCER CT.

CRIQU

MW-15C
MW-15B
MW-15A

TRAFALGAR CT.

STRATHMORE CT.

WICKET CT.

MW-22A MW-22B

VINCENT ROAD

BANCROFT RD.

MW-04

MW-07

MW-01

MW-03
TW-3

TW-2

SVE-1
TW-4

MW-14B
MW-14A

MW-09B

MW-19C MW-19A
MW-19B

HOOKSTON ROAD

BERMUDA DRIVE

STIMEL DRIVE

RUGBY CT.

BRIDGE STREET

C. C. C. F. C. D.

MW-08B MW-08A

MW-21A

MW-21B

MW-20A
MW-20B

MW-05

TW-1

MW-13B
MW-13A

BERMUDA CT. BAIRD CT.

MOUNTBATTEN COURT

BENTLEY

NUALA

MW-11A
MW-11B

MW-02

MW-18A
MW-18B

ST. LOUIS DRIVE

ST. LOUIS CT.

ABBEY CT.

MW-12A
MW-12B

VINCENT ROAD

BANCROFT ROAD

FOXGLOVE

IVYWOOD

TRAUD DRIVE

TRAUD CT.

LORD CT.

MW-06

MAYHEW WAY

LEGEND

◆ A-Zone Monitoring Well
◆ B-Zone Monitoring Well
◆ C-Zone Monitoring Well
▬ ▬ Hookston Station Parcel
    Property Boundary

▲ Test Well
SVE-1 ▲ Soil Vapor Extraction Well

N

0   300
FEET

Figure G-1
Well Location Map
Hookston Station
Pleasant Hill, California

ERM   *06/06*

Tables

Well ID	Groundwater Zone	Pumping Well Discharge, gpm	Screen Interval, ft bgs	Distance from Pumping Well ft	Saturated Thickness ft	Transmissivity T cm^2/s	Transmissivity T ft^2/day	Hydraulic Conductivity K cm/s	Hydraulic Conductivity K ft/day	Storativity S [unitless]
ERM Constant Rate Pump Test - MW-5 (Screened 10 to 30 feet bgs)										
Single Well Analysis (Papadopulos-Cooper)										
MW-5	A-Zone	4	10-30	0	16	0.59	56	1.21E-03	3.4	n/a
ERM Slug Tests (Bouwer-Rice)										
MW-5	A-Zone	--	10-30	--	16	7.61	7.1E+02	1.56E-02	44	n/a
MW-7	A-Zone	--	15-35	--	20	1.30	1.2E+02	2.13E-03	6	n/a
MW-14A	A-Zone	--	29-34	--	21	1.46	1.4E+02	2.28E-03	6	n/a
MW-15A	A-Zone	--	15-25	--	12	*	*	*	*	*
MW-16A	A-Zone	--	15-25	--	15	1.30	1.2E+02	2.84E-03	8	n/a
MW-17A	A-Zone	--	20.7-30.7	--	12	3.60	3.3E+02	9.84E-03	28	n/a
Average Bouwer-Rice Results						3.1	2.84E+02	6.54E-03	19	n/a

Notes:
bgs = Below ground surface
cm/s = Centimeters per second
cm^2/s = Square centimeters per second
ft = Feet
ft/day = Feet per day
ft^2/day = Square feet per day
gpm = Gallons per minute
n/a = Not applicable
* Slug tests were performed at MW-15A. The test results were inconclusive and therefore are not presented above.

Well ID	Ground Water Zone	Pumping Well Discharge, gpm	Screen Interval, ft bgs	Distance from Pumping Well, ft	Saturated Thickness, ft	Transmissivity T [cm²/s]	Transmissivity T [ft²/day]	Hydraulic Conductivity K [cm/s]	Hydraulic Conductivity K [ft/day]	Storativity S [unitless]
ERM Constant Rate Pump Test - TW-1 (Screened 45 to 75 feet bgs)										
Theis Time-Drawdown Analysis (Confined)										
MW-13B	B-Zone	25	45-55	12	30	8	7.46E+02	8.59E-03	24	1.34E-03
MW-8B	B-Zone	25	45-60	300	30	10	9.39E+02	1.08E-02	31	2.55E-04
MW-15B	B-Zone	25	49-59	990	30	15	1.39E+03	1.60E-02	45	2.22E-04
Cooper-Jacob Time-Drawdown Analysis (Confined)										
MW-13B	B-Zone	25	45-55	12	30	8	7.71E+02	8.88E-03	25	6.05E-04
MW-8B	B-Zone	25	45-60	300	30	11	1.03E+03	1.18E-02	33	2.25E-04
MW-15B	B-Zone	25	49-59	990	30	20	1.86E+03	2.15E-02	61	2.75E-03
Cooper-Jacob Distance-Drawdown Analysis (Confined)										
1,000 seconds (MW-13B, MW-8B, MW-15B)	B-Zone	25	Various	15, 300 and 990	30	25	2.38E+03	2.75E-02	78	9.44E-05
10,000 seconds (MW-13B, MW-8B, MW-15B)	B-Zone	25	Various	15, 300 and 990	30	18	1.74E+03	2.00E-02	57	1.22E-04
20,000 seconds (MW-13B, MW-8B, MW-15B)	B-Zone	25	Various	15, 300 and 990	30	11	1.04E+03	1.20E-02	34	1.70E-04
Recovery Analyses (Theis, Confined)										
MW-13B	B-Zone	25	45-55	12	30	7	6.77E+02	1.56E-02	44	n/a
MW-8B	B-Zone	25	45-60	300	30	9	8.84E+02	2.04E-02	58	n/a
MW-15B	B-Zone	25	49-59	990	30	25	2.35E+03	5.41E-02	153	n/a
Average Theis Time-Drawdown Results						11	1.02E+03	1.18E-02	33	6.06E-04
Average Cooper-Jacob Time-Drawdown Result						13	1.22E+03	1.41E-02	40	1.19E-03
Average Cooper-Jacob, Distance-Drawdown Results						18	1.72E+03	1.98E-02	56	1.29E-04
Average Recovery Analysis (Theis, Confined) Results						14	1.30E+03	3.00E-02	85	n/a
Overall Average Results						**14**	**1.32E+03**	**1.89E-02**	**54**	**6.43E-04**
ERM Slug Tests (Bouwer-Rice)										
MW-8B	B-Zone	--	45-60	--	9	2.6	2.4E+02	9.55E-03	27	n/a
MW-14B	B-Zone	--	40-50	--	8	1.4	1.3E+02	5.87E-03	17	n/a
MW-15B	B-Zone	--	49-59	--	10	0.5	4.5E+01	1.59E-03	5	n/a
MW-16B	B-Zone	--	35-45	--	9	2.1	2.0E+02	7.83E-03	22	n/a
MW-17B	B-Zone	--	44-54	--	10	0.4	3.8E+01	1.33E-03	4	n/a
Average Bouwer-Rice Results						1.4	1.32E+02	5.23E-03	15	n/a

Key:

ft = Feet
bgs = Below ground surface
ft/day = Feet per day
ft²/day = Square feet per day

cm/s = Centimeters per second
cm²/s = Square centimeters per second
gpm = Gallons per minute

Attachment A
Well Construction Logs

ERM
1777 Botelho Drive
Suite 260
Walnut Creek, California 94596
(925) 946−0455

BOREHOLE LOG

Project Number: 0020557.10

Project Name: UP Hookston Station

Location: Pleasant Hill

Contractor: Gregg

Drilling Method: Hollow Stem Auger

Logged By: A. Cole

Date(s): 04/05/06

Initial Water Level: 26.50'

X−Coordinate: NA

Y−Coordinate: NA

Total Depth: 77.00'

Completed Depth: 75.00'

Borehole Dia.: 10.00in

Blank Casing:			
type: Sch 40 PVC	dia: 2.00in	fm: 0.50'	to: 45.00'

Screens:				
type: Slotted	size: 0.020in	dia: 2.00in	fm: 45.00'	to: 75.00'

Annular Fill:		
type: Grout	fm: 0.75'	to: 39.00'
type: Bentonite	fm: 39.00'	to: 42.00'
type: #2/12 Sand Filter	fm: 42.00'	to: 77.00'

Depth (ft)	Graphic Log	USCS Code	Well Construction	Sample Recovery	Blow Count	PID (ppm)	Soil Description and Observations
		CL					Base rock, gravelly sand, 0.5−2.0" subangular gravel.
							CLAY (CL): black, trace silt, low plasticity, soft, wet.
5					6 9 12	0.0	CLAY (CL): olive brown, some silt, trace fine grained sand, medium plasticity, slightly moist.
10		SM			5 7 8	0.0	SILTY SAND (SM): light brown, very fine grained sand, some clay, soft, slightly moist.
15		CL			8 12 16	0.0	CLAY (CL): olive brown, some fine grained sand, stiff, low plasticity, dry.
					12 15 20	0.0	CLAY (CL): dark brown, trace fine grained sand, stiff, medium plasticity, dry.
20							
25					8 14 19	0.0	CLAY (CL): as above, increased moisture.
30		SM			12 17 21 10	0.0	SILTY SAND (SM): olive brown, fine to medium grained sand, trace organics (roots), dense, wet.
		ML			18 46	0.0	SILT (ML): olive, some fine grained sand, trace organics (roots), stiff, wet.
35		CL			10 14 16	0.0	CLAY (CL): black, trace fine grained sand, very stiff, low plasticity, dry.
		SM			14 20 27 9 18	0.0	SILTY SAND (SM): gray brown, fine grained sand, dense, wet.
							SILTY SAND (SM): as above.
		CL			20 19 27 37		CLAY (CL): black/gray, trace fine grained sand, white organic fibers, very stiff, low plasticity, dry.

BOREHOLE LOG

ERM
1777 Botelho Drive
Suite 260
Walnut Creek, California 94596
(925) 946-0455

Site Id: TW-1

Page 2 of 2

Project Number: 0020557.10

Project Name: UP Hookston Station

Location: Pleasant Hill

Contractor: Gregg

Drilling Method: Hollow Stem Auger

Logged By: A. Cole

Date(s): 04/05/06

Initial Water Level: 26.50'

X-Coordinate: NA

Y-Coordinate: NA

Total Depth: 77.00'

Completed Depth: 75.00'

Borehole Dia.: 10.00in

Blank Casing: type: Sch 40 PVC	dia: 2.00in	fm: 0.50'	to: 45.00'
Screens: type: Slotted size: 0.020in	dia: 2.00in	fm: 45.00'	to: 75.00'

Annular Fill:		
type: Grout	fm: 0.75'	to: 39.00'
type: Bentonite	fm: 39.00'	to: 42.00'
type: #2/12 Sand Filter	fm: 42.00'	to: 77.00'

Depth (ft)	Graphic Log	USCS Code	Well Construction	Sample Recovery	Sample No.	PID (ppm)	Soil Description and Observations
					26 24 39	0.0	CLAY (CL): as above.
					6 18 37		CLAY (CL): tan, medium grained sand, trace dark organic fibers, very stiff, low to medium plasticity, dry.
45		SM			19 25 31	0.0	SILTY SAND (SM): gray, fine to medium grained sand, biotite-rich, dense, wet.
		SW			13 18 21		WELL GRADED SAND (SW): gray brown, medium to coarse grained sand, some 0.25-0.5" rounded gravel, loose, wet.
		SP			17 19 23		POORLY GRADED SAND (SP): light brown, medium grained sand, trace 0.25" gravel, wet.
					21 23 50-6		
50					21 33 50-1		POORLY GRADED SAND (SP): light brown, fine grained sand, dense, wet.
					17 16 38		POORLY GRADED SAND (SP): as above.
							No recovery.
		SW			19 25 36		WELL GRADED SAND (SW): olive brown, fine to medium grained sand, dense, wet.
55					18 15 40		
					21 29 26		
					25 31 50-3		WELL GRADED SAND (SW): gray brown, fine to coarse grained sand, dense, wet.
60					36 50-3		
					25 46 39		WELL GRADED SAND (SW): as above.
		SP			21 33 38		POORLY GRADED SAND (SP): gray brown, medium grained sand, dense, wet.
65					22 28 33		POORLY GRADED SAND (SP): as above.
					26 33 40		
		SW			34 47 50-2		WELL GRADED SAND (SW): gray brown, medium to coarse grained sand, trace rounded gravel, dense, wet.
70					23 27 50-6		WELL GRADED SAND (SW): as above.
		SP					POORLY GRADED SAND (SP): brown, medium grained sand, trace silt, wet.
75					13 40 50-3		
		CL					CLAY (CL): olive brown, some fine grained sand, stiff, low plasticity, dry. Total Depth - 77.0' bgs

Attachment B
Standard Operation Procedure –
In Situ Aquifer Tests

UPRR Hookston Station

Standard Operating Procedure
In Situ Aquifer Tests
Pleasant Hill, California

April 2006

0020557.10

Environmental Resources Management
1777 Botelho Drive, Suite 260
Walnut Creek, California 94596

1.0 PURPOSE AND SCOPE

The purpose of this document is to define the standard operating procedure (SOP) for performing in situ aquifer tests (slug tests) at the UPRR Hookston Station site in Pleasant Hill, California.

This SOP documents the procedures to be followed for conducting slug tests at the site. Any deviation from this procedure should be thoroughly documented and evaluated prior to proceeding, to ensure that the data quality objectives are met.

This SOP serves as a reference to the project Workplan and applies to all slug test activities conducted by ERM personnel or their subcontractors. This Workplan is to be strictly followed, and any modifications to this SOP shall be approved by the Project Manager (PM) in advance.

2. 0   *RESPONSIBILITIES AND QUALIFICATIONS*

The PM is responsible for assigning project staff to complete the slug test activities at the site and to assure that this and any other appropriate procedures are followed by all project personnel.

The project staff assigned to the slug test is responsible for completing all tasks according to this and other appropriate procedures and must report any deviations from the procedure or nonconformance to the PM or Project Quality Assurance/ Quality Control (QA/QC) Officer.

Only qualified personnel shall be allowed to perform this procedure or supervise subcontractors hired to perform this procedure. At a minimum, ERM employees qualified to perform slug tests will be required to:

- Read this SOP;

- Indicate to the PM that they understand all procedures contained in this SOP;

- Have completed the OSHA 40-hour training course and/or 8-hour refresher course, as appropriate; and

- Have slug test experience generally consistent with the procedures described in this SOP.

3. 0   PROCEDURES FOR SLUG TESTS

3.1   EQUIPMENT LIST

The following list of equipment and supplies are required to perform slug tests.

_____	Pressure transducer and data logger
_____	Electronic water level probe
_____	A solid slug (such as PVC pipe filled with sand) of known volume for falling-head slug tests
_____	A solid or hollow slug (such as a bailer) of known volume for rising-head slug tests
_____	Rope
_____	Well construction logs
_____	5-gallon bucket
_____	Decontamination materials
_____	Field book
_____	Duct tape

3.2   TEST SET-UP

The following procedures will be followed for setting up slug tests.

1) Measure the depth to water and record the level in the field notebook.

2) Lower the transducer into the well. The transducer should be placed so that slug addition or removal does not interfere with the transducer and that the water level does not fall below the transducer. Be sure the psi setting on the transducer is greater than the water column and estimated increase in water column from the slug (1 psi equals 2.31 feet of water).

3) Secure the transducer by taping or tying the cable to the well or other fixed object.

4) Prepare the transducer by specifying:

- Reference value equal to zero; and

- Readings collected on logarithmic scale (time interval between readings should be at least one reading per second for the first 10 minutes and lengthen over time).

5) Check the level on the transducer and record in the field book.

3.3 FALLING-HEAD TEST PROCEDURES

If falling-head slug tests are to be performed, the following steps should be followed after all the Test Set-Up procedures (Steps 1 through 5) have been completed.

6) Lower the slug inside the well to a level above the water table. Start the pressure transducer, wait for five seconds, and then instantaneously lower the slug into the water column. Be careful not to produce a "splash" when lowering the slug and make sure the entire slug volume is entered into the water column.

7) Allow the pressure transducer to record data until the water level stabilizes. Use a laptop computer to determine when stabilization has been achieved. Occasionally manually measure the water level with a water-level indicator and record the exact time during the test to calibrate the transducer data.

8) Stop the pressure transducer when the water level has stabilized.

9) Measure depth to water and record in the field notebook.

3.4 RISING-HEAD TEST PROCEDURES

The following steps should be followed after all the Test Set-Up procedures (Steps 1 through 5) and Falling-Head Test Procedures (Steps 6 through 9, if Falling-Head slug tests are performed) have been completed.

10) Gently lower a slug into the well below the static water level. Allow the water level to recover to static conditions. Confirm that the slug is completely submerged within the water column. If a falling-head test was previously completed, a rising-head test can be iniated once the water levels have recovered to static conditions following the rising-head test.

11) Prepare the transducer by specifying:

- Reference value equal to zero; and

- Readings collected on logarithmic scale.

12) Start the pressure transducer, wait for five seconds, and then instantaneously remove the slug from the well. Be careful not to produce a "wave" when removing the slug and make sure the slug is completely removed from the well.

13) Allow the pressure transducer to record data until the water level stabilizes. Use a laptop computer to determine when stabilization has been achieved, occasionally manually measure the water level with a water-level indicator and record the exact time during the test to calibrate the transducer data.

14) Stop the pressure transducer when the water level has stabilized.

15) Measure depth to water and record in the field notebook.

4.0   *DECONTAMINATION*

All non-disposable equipment will be property decontaminated prior to beginning the slug tests and between use at each well. Nitrile gloves will be worn whenever handling the equipment. The decontamination procedure is as follows:

- Wash equipment in an Alconox (or equivalent) and water soution using a brush or clean cloth to ensure removal of all contaminants.

- Rinse equipment in fresh tap water.

- Rinse equipment with a deionized water rinse.

- Dry equipment with a paper towel and place in clean plastic, if appropriate.

Decontamination activities will be noted for every sample location in the field note book.

5.0   DOCUMENTATION

For each slug test, all the pertinent data will be recorded in the field notebook and/or data collection forms. This information should include the following for each slug test:

- Personnel's name;

- Slug test location;

- Description of slug, including volume and materials;

- Static ground water level;

- Date and time of data logger installation;

- Date and time of slug installation and/or removal;

- Manual water level measurements, including date and time;

- Date and time of conclusion of slug test; and

- Weather conditions.

Attachment C
Standard Operation Procedure –
Aquifer Pump Tests

UPRR Hookston Station

Standard Operating Procedure
Aquifer Pump Tests
Pleasant Hill, California

April 2006

0020557.10

Environmental Resources Management
1777 Botelho Drive, Suite 260
Walnut Creek, California 94596

TABLE OF CONTENTS

1.0   *PURPOSE AND SCOPE*

The purpose of this document is to define the standard operating procedure (SOP) for performing aquifer pump tests at the UPRR Hookston Station site in Pleasant Hill, California.

This SOP documents the procedures to be followed for conducting pump tests at the site. Any deviation from this procedure should be thoroughly documented and evaluated prior to proceeding, to ensure that the data quality objectives are met.

This SOP serves as a reference to the project Workplan and applies to all pump test activities conducted by ERM personnel or their subcontractors. This Workplan is to be strictly followed, and any modifications to this SOP shall be approved by the Project Manager (PM) in advance.

2. 0   *RESPONSIBILITIES AND QUALIFICATIONS*

The PM is responsible for assigning project staff to complete the pump test activities at the site and to assure that this and any other appropriate procedures are followed by all project personnel.

The project staff assigned to the pump test is responsible for completing all tasks according to this and other appropriate procedures and must report any deviations from the procedure or nonconformance to the PM or Project Quality Assurance/ Quality Control (QA/QC) Officer.

Only qualified personnel shall be allowed to perform this procedure or supervise subcontractors hired to perform this procedure. At a minimum, ERM employees qualified to perform pump tests will be required to:

- Read this SOP;

- Indicate to the PM that they understand all procedures contained in this SOP;

- Have completed the OSHA 40-hour training course and/or 8-hour refresher course, as appropriate; and

- Have pump test experience generally consistent with the procedures described in this SOP.

3.0   PUMP TEST PROCEDURES

Aquifer tests will consist of four distinct monitoring phases. Background water levels must first be monitored to identify any extraneous stresses that may impact the test data. A step-drawdown test is then performed to identify the ideal pumping rate for the tested well. The constant-rate test is subsequently performed to monitor the effects of pumping and to calculate hydraulic properties of the aquifer. Finally, aquifer recovery is monitored to confirm the results of the constant-rate pumping test.

The scope of work for each phase of the aquifer test is described below, as well as equipment to be utilized.

3.1   PUMP TEST EQUIPMENT

Typical equipment for pump testing includes the following items:

- Submersible pump;
- Water flow measuring device(s);
- Water level measuring device;
- Pressure transducers;
- Watch or stop watch;
- Data recording forms and data logger;
- Discharge water treatment system/transfer lines;
- Barometer or access to barometric pressure data; and
- Decontamination equipment.

3.2   PRE-PUMPING (BACKGROUND) MONITORING

For each pump test, water levels will be monitored in specified wells for approximately 1 day prior to the start of each test. Pre-pumping water levels will be collected every 10 minutes using electronic transducers. These data will be used to correct the aquifer test data from changes in atmospheric pressure or local uncontrolled aquifer stresses, such as pumping from nearby water supply wells if present. If pumping from

nearby water supply wells appears to affect water levels within the monitoring area, the pumping schedules for relevant wells during the subsequent pumping and recovery tests will be documented.

3.3   *STEP-DRAWDOWN PUMPING TEST/FLOWMETER TESTING*

A step-drawdown test may be performed at each extraction well prior to initiating the constant-rate pumping test to determine the optimal flow rate for the well. A combined transducer/data logger will be installed in the extraction well prior to the start of the step-drawdown test. Water levels will also be measured manually with an electric sounder to calibrate depths measured using the pressure transducer.

During the step-drawdown test, the well will be pumped at varying rates. The duration of each rate will be determined at the time of the test, but typically each rate is maintained until drawdown approximately stabilizes. During the test, a plot of drawdown versus elapsed time will be created to determine the duration of each pumping rate and to estimate the rate increase for the next step.

3.4   *CONSTANT-RATE PUMPING TEST*

After water levels have recovered from the step-drawdown test to their pre-test static levels, the constant-rate pumping test will be initiated. Each pump test will utilize one extraction (pumping) well and several observation wells.

Water levels will be measured at logarithmic time intervals in the pumped well and surrounding observation wells. Water levels will be measured in the pumping and observation wells with electronic transducers and data loggers at least as frequently as follows:

Elapsed Time (minutes)	Frequency of Measurement
0 – 10	10 seconds
10 – 30	1 minute
30 - 120	10 minutes
120 - end of test	30 minutes

Electronically measured water levels will be checked periodically with manual measurements. Additional wells in the vicinity of the pumping

well may also be manually monitored using an electronic water level meter.

The pumping rate will be determined based on the step-drawdown test data. The pump rate will be monitored with a flow meter.

The duration of each test will be based on the time anticipated to influence the designated observation wells, with allowance for delayed drainage. The actual duration of a test will be determined in the field based on the drawdown observed over time.

3.5   POST-PUMPING (RECOVERY) MONITORING

Upon completion of the constant rate pump test, recovery of water levels in the extraction and observation wells will be monitored. Measurement frequency will be similar to that of the measurements taken during the pumping portion of the test, as described above. Recovering water levels will be plotted in the field and used to determine the duration of the monitoring time interval. Approximately 90 percent of drawdown will be deemed a sufficient degree of recovery to terminate the test.

3.6   INVESTIGATIVE DERIVED WASTES

Investigative derived wastes (IDW) will include pumping water and decontamination water. All IDW will be containerized on-site in 55-gallon drums or other appropriate storage vessels until waste characterization is complete and off-site disposal can be arranged.

4.0 *DECONTAMINATION*

All non-disposable equipment will be properly decontaminated prior to beginning any tasks associated with the pump tests (including background measurements) and between use at each well. Nitrile gloves will be worn whenever handling the equipment. The decontamination procedure is as follows:

- Wash equipment in an Alconox (or equivalent) and water soution using a brush or clean cloth to ensure removal of all contaminants.

- Rinse equipment in fresh tap water.

- Rinse equipment with a deionized water rinse.

- Dry equipment with a paper towel and place in clean plastic, if appropriate.

Decontamination activities will be noted for every sample location in the field note book.

5.0   *DOCUMENTATION*

For phase of the pump test, all pertinent data will be recorded in the field notebook and/or data collection forms. This information should include the following for each pump test:

- Personnel's name;

- Well location;

- Static ground water level;

- Date and time of data logger installation;

- Data and time data logger is turned on;

- Date and time pumping is initiated;

- Pumping rate;

- Manual water level measurements, including date and time;

- Date and time pumping is stopped;

- Date and time data loggers are turned off; and

- Weather conditions.

Attachment D
Aquifer Test Analyses
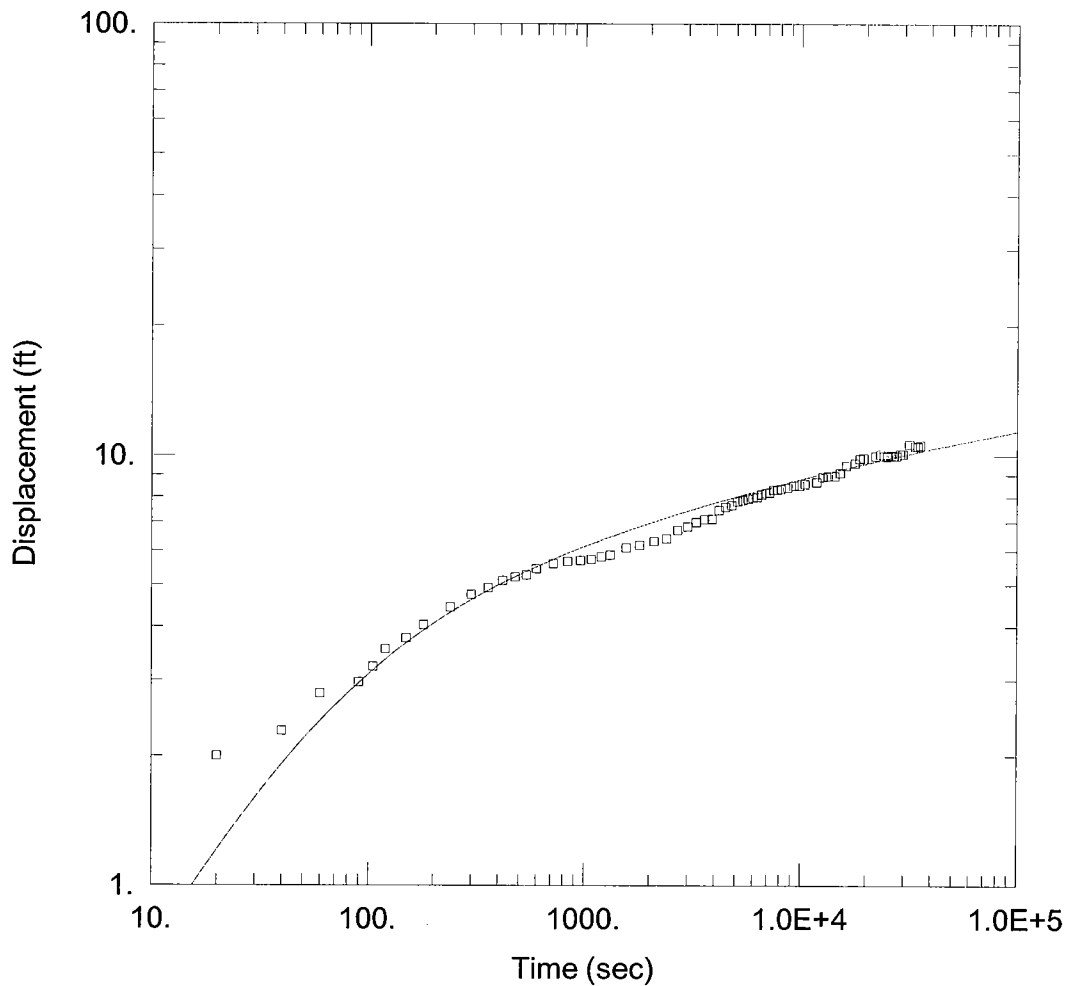
A-ZONE PUMP TEST

Data Set: C:\Program Files\HydroSOLVE\AQTESOLV for Windows Demo 3.5\Hookston MW-5.aqt
Date: 06/23/06   Time: 11:25:04

PROJECT INFORMATION

Company: ERM-West, Inc.
Client: Hookston Station
Project: 0020557.10
Location: Pleasant Hill, CA
Test Well: MW-5
Test Date: 4/10/06

AQUIFER DATA

Saturated Thickness: 16. ft   Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
MW-5	0	0	□ MW-5	0	0

SOLUTION

Aquifer Model: Confined   Solution Method: Papadopulos-Cooper

T   = 0.5914 cm^2/sec   S   = 0.01192
r(w) = 0.666 ft   r(c) = 0.1666 ft
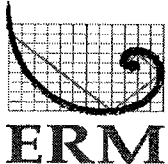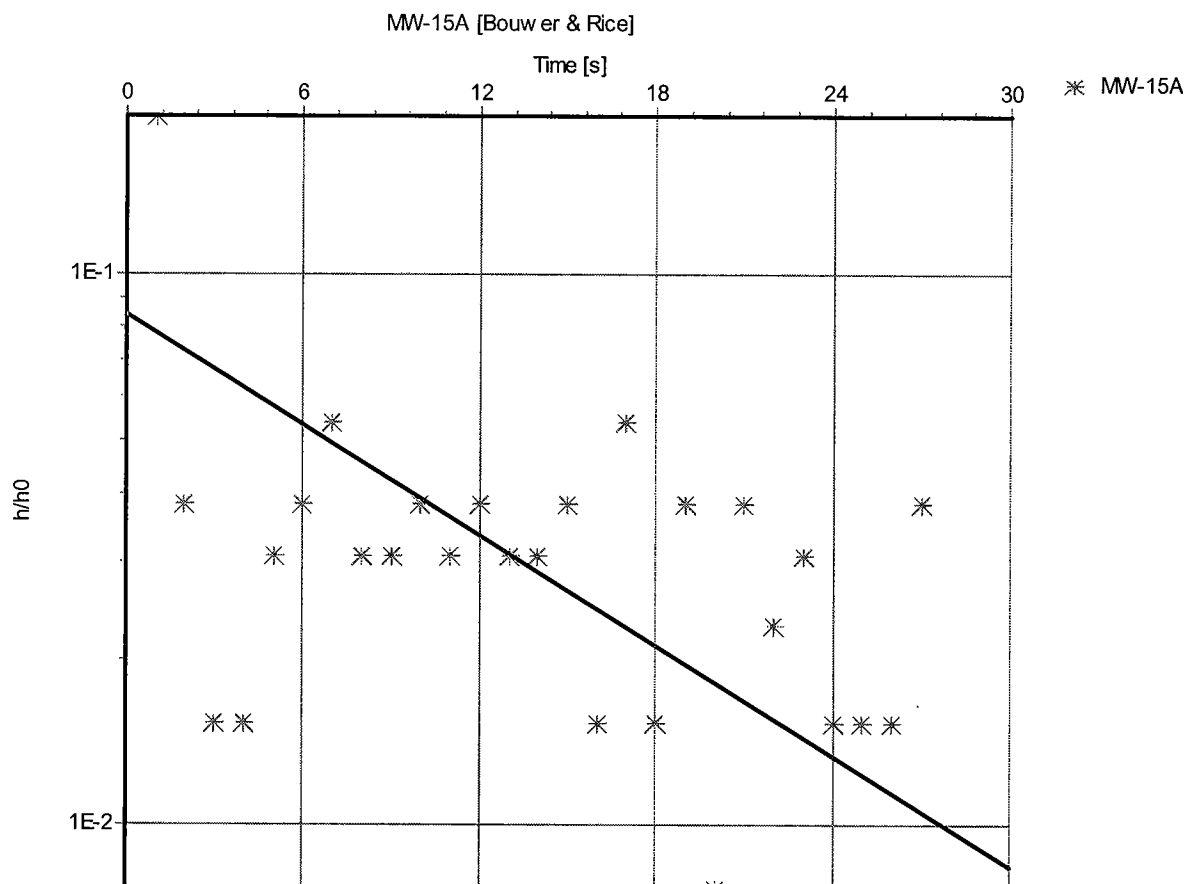
ERM-West, Inc.
1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

MW-5 [Bouwer & Rice]

Time [s]

h/h0

● MW-5
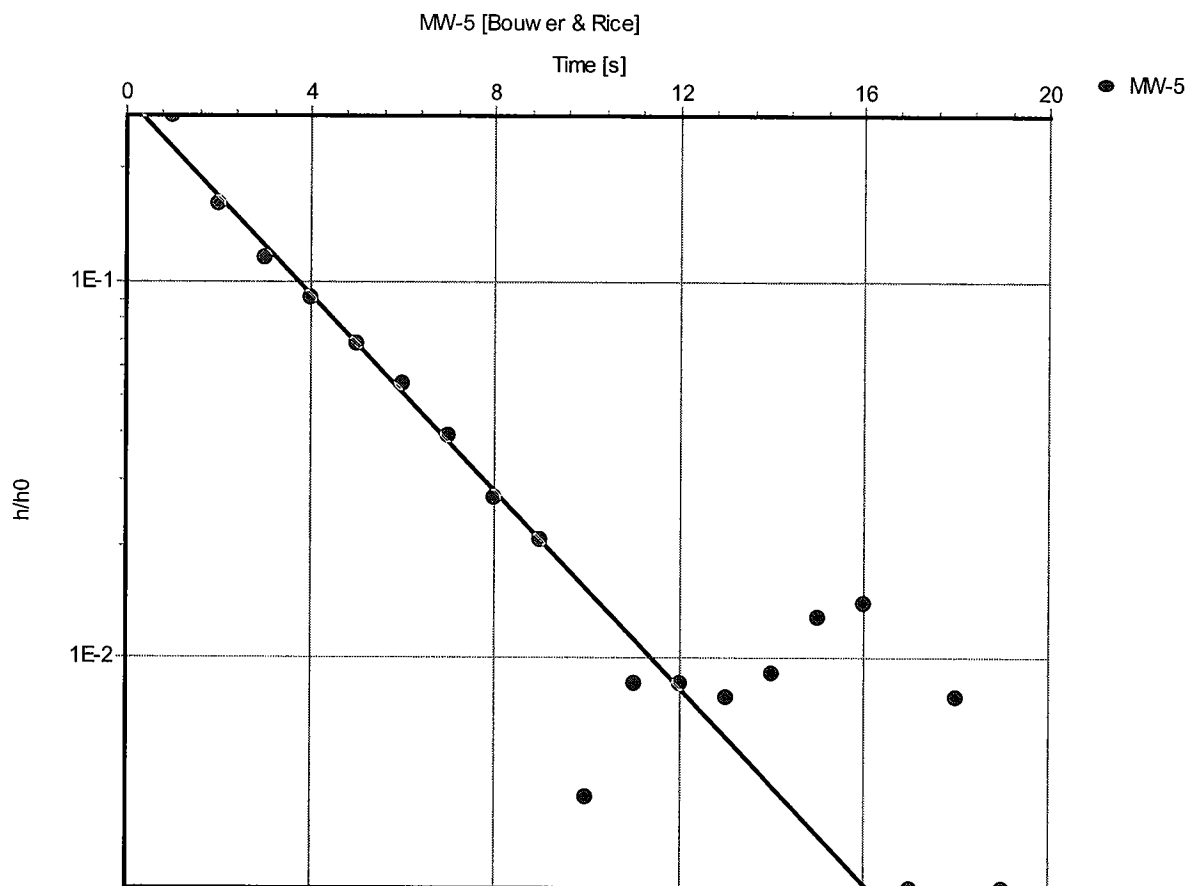
Slug Test: **MW-5**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity: 1.56E-2 [cm/s]

Test parameters:

Test Well:	MW-5		Aquifer Thickness:	16 [ft]
Casing radius:	0.1666 [ft]		Gravel Pack Porosity (%)	25
Screen length:	20 [ft]			
Boring radius:	0.666 [ft]			
r(eff):	0.363 [ft]			

Comments:

Evaluated by:

Evaluation Date: 5/1/2006
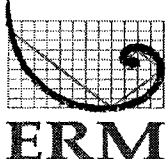
Slug Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	
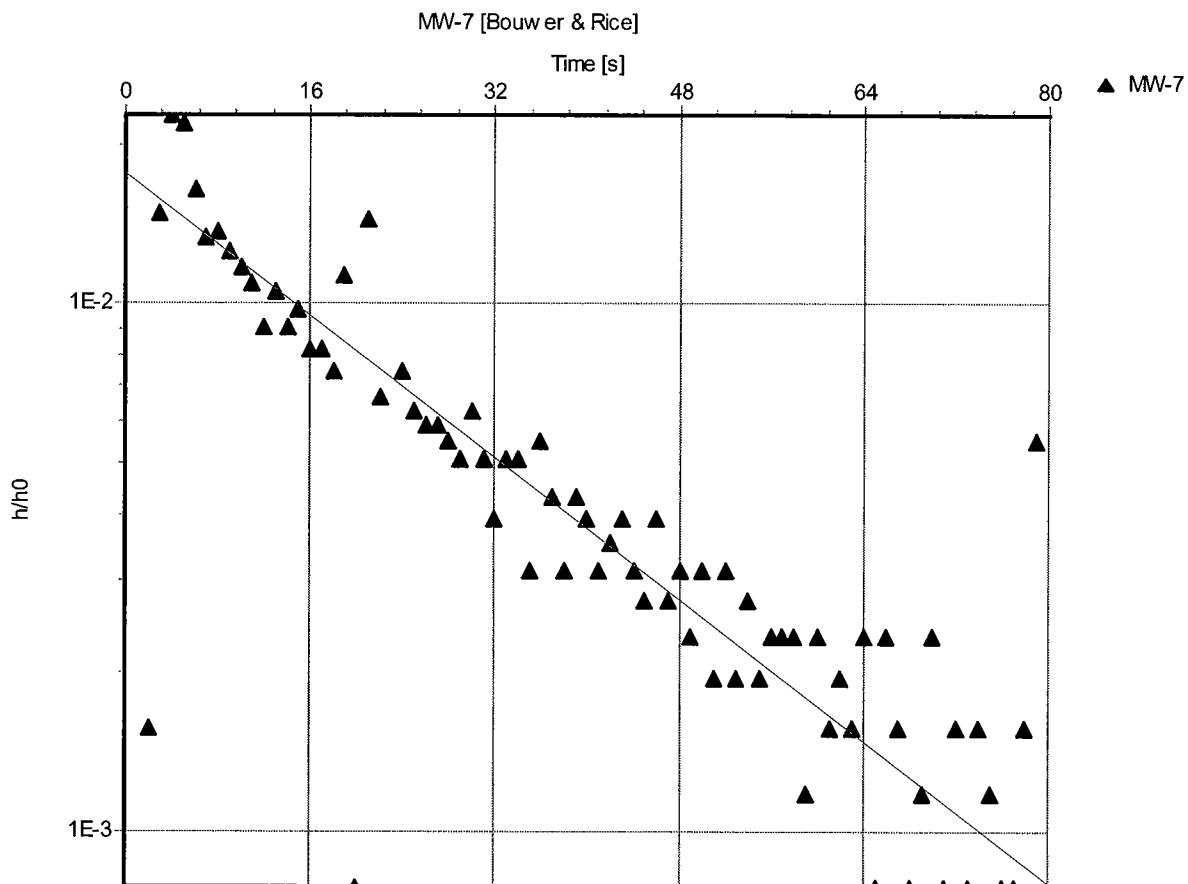
MW-7 [Bouwer & Rice]

Slug Test:	**MW-7**	
Analysis Method:	**Bouwer & Rice**	

Analysis Results:

Conductivity: 2.13E-3 [cm/s]

Test parameters:

Test Well:	MW-7		Aquifer Thickness:	20 [ft]
Casing radius:	0.1666 [ft]		Gravel Pack Porosity (%)	25
Screen length:	20 [ft]			
Boring radius:	0.666 [ft]			
r(eff):	0.363 [ft]			

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

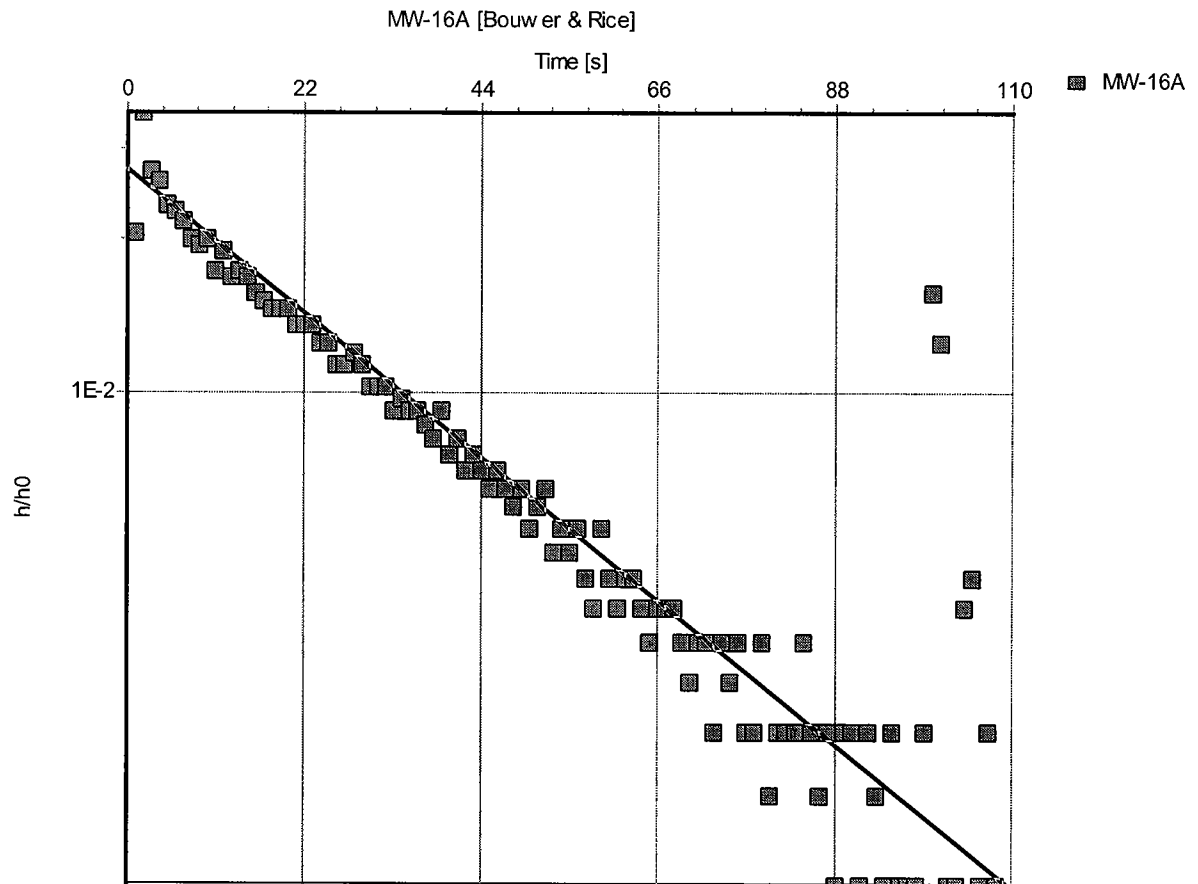**ERM-West, Inc.**
1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
ERM 925-946-0455
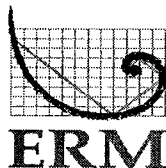
Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:
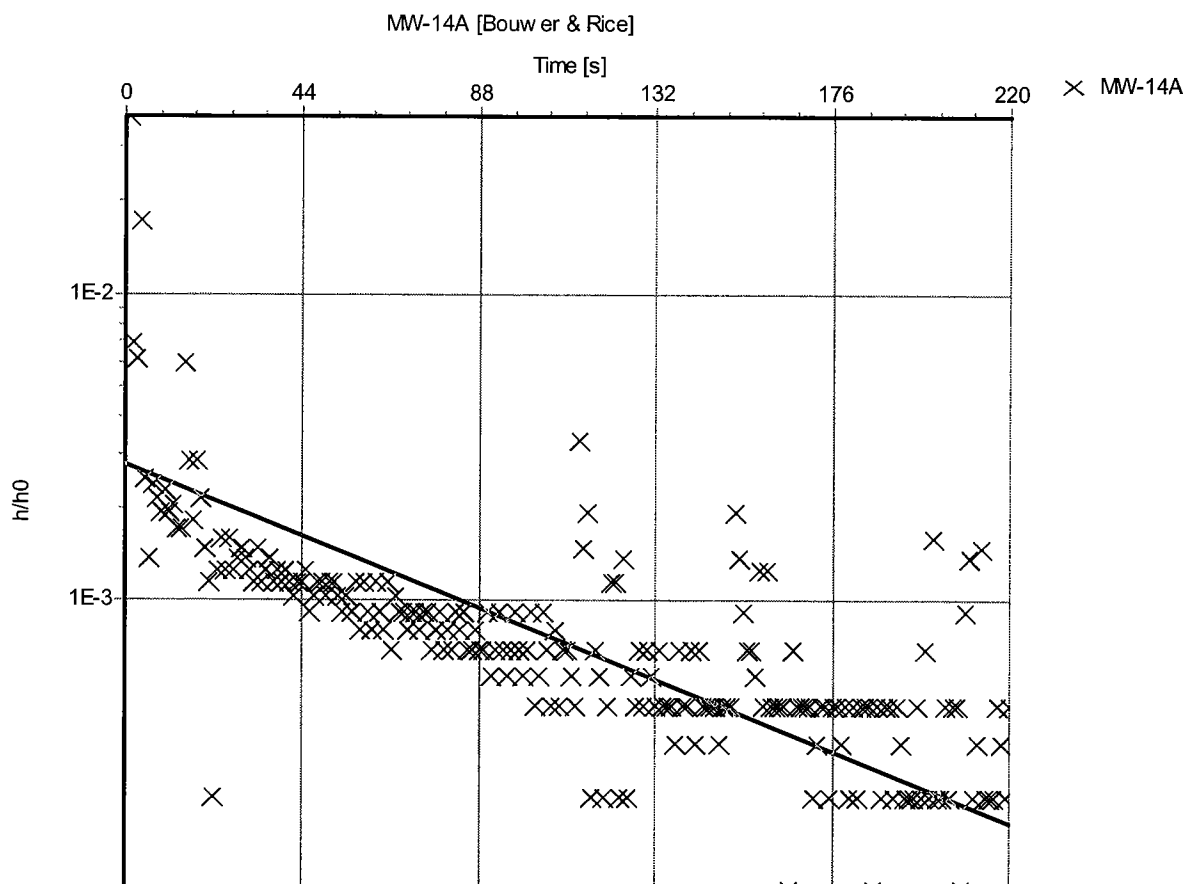
MW-14A [Bouw er & Rice]

Slug Test:	**MW-14A**
Analysis Method:	**Bouwer & Rice**

Analysis Results:

	Conductivity:	2.28E-3 [cm/s]

Test parameters:

Test Well:	MW-14A	Aquifer Thickness:	21 [ft]
Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
Screen length:	5 [ft]		
Boring radius:	0.666 [ft]		
r(eff):	0.363 [ft]		
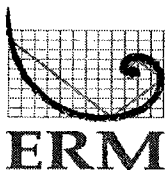
Comments:

Evaluated by:

Evaluation Date: 5/1/2006

ERM-West, Inc.
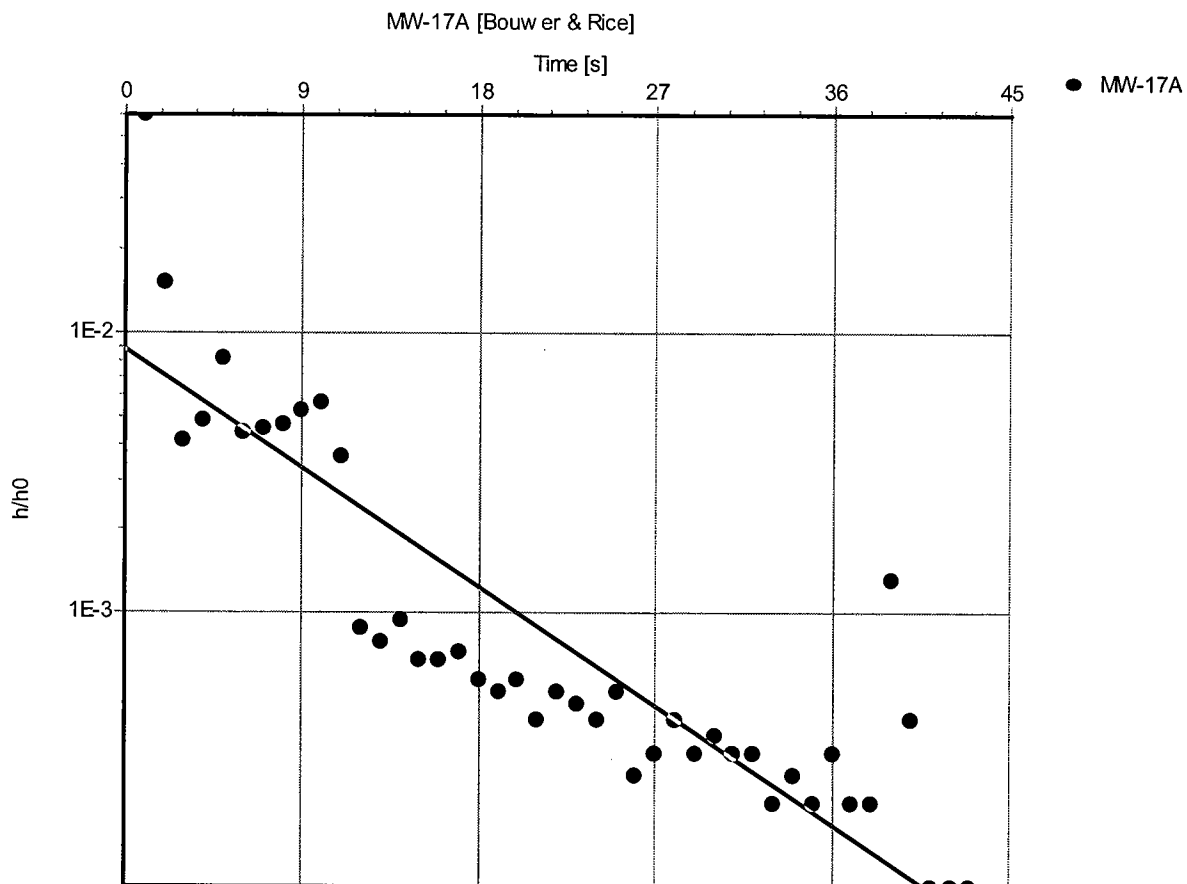1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

MW-15A [Bouwer & Rice]

Slug Test: **MW-15A**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity:	6.94E-3 [cm/s]

Test parameters:

Test Well:	MW-15A	Aquifer Thickness:	12 [ft]
Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
Screen length:	10 [ft]		
Boring radius:	0.666 [ft]		
r(eff):	0.363 [ft]		

Comments:

Evaluated by:

Evaluation Date: 5/1/2006
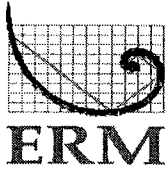
Slug Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

MW-16A [Bouwer & Rice]

Slug Test: **MW-16A**

Analysis Method: **Bouwer & Rice**

Analysis Results:		Conductivity:	2.84E-3 [cm/s]

Test parameters:	Test Well:	MW-16A	Aquifer Thickness:	15 [ft]
	Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
	Screen length:	10 [ft]		
	Boring radius:	0.666 [ft]		
	r(eff):	0.363 [ft]		

Comments:

Slug Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

MW-17A [Bouwer & Rice]

Slug Test:	**MW-17A**
Analysis Method:	**Bouwer & Rice**

Analysis Results:

Conductivity: 9.84E-3 [cm/s]

Test parameters:

Test Well:	MW-17A	Aquifer Thickness:	12 [ft]
Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
Screen length:	10 [ft]		
Boring radius:	0.666 [ft]		
r(eff):	0.363 [ft]		

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

ERM-West, Inc.
1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

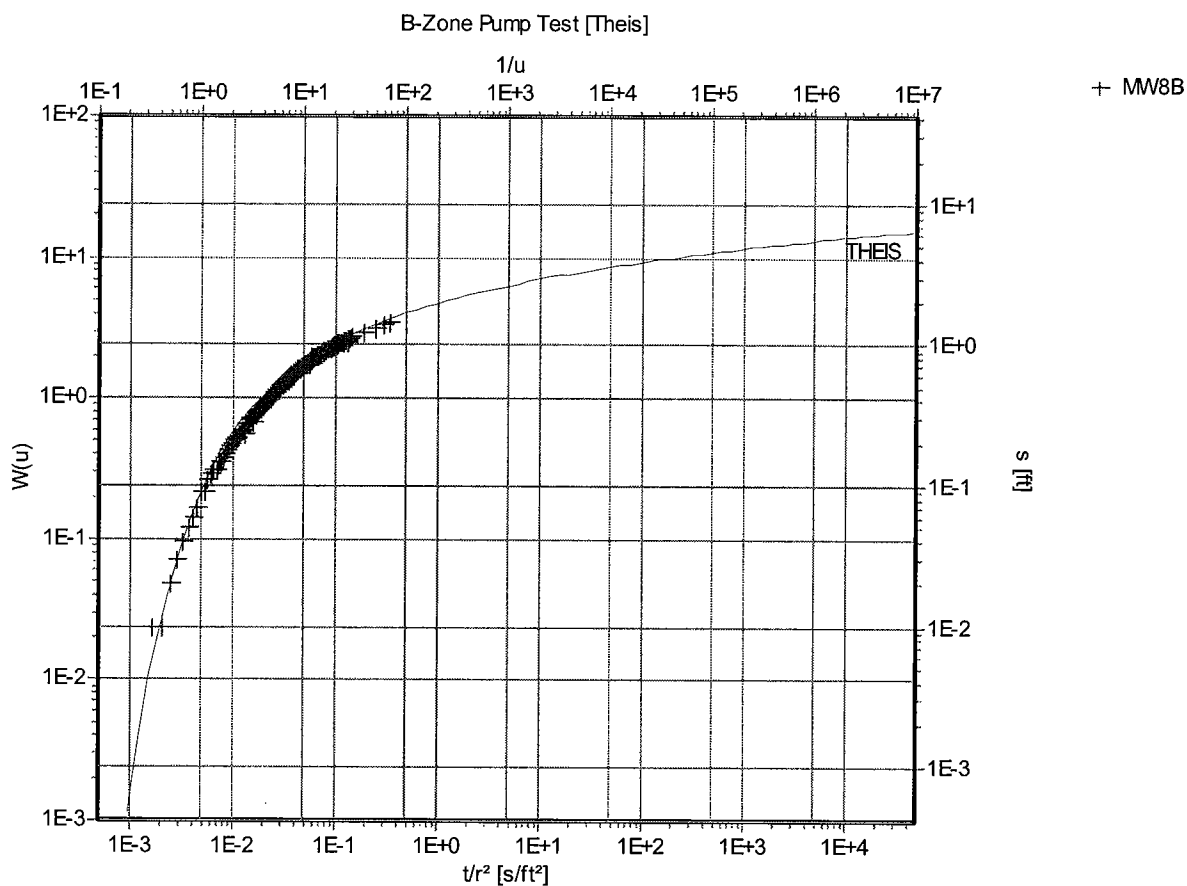**ERM**

Pumping Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

B-Zone Pump Test [Theis]

※ MW-13B
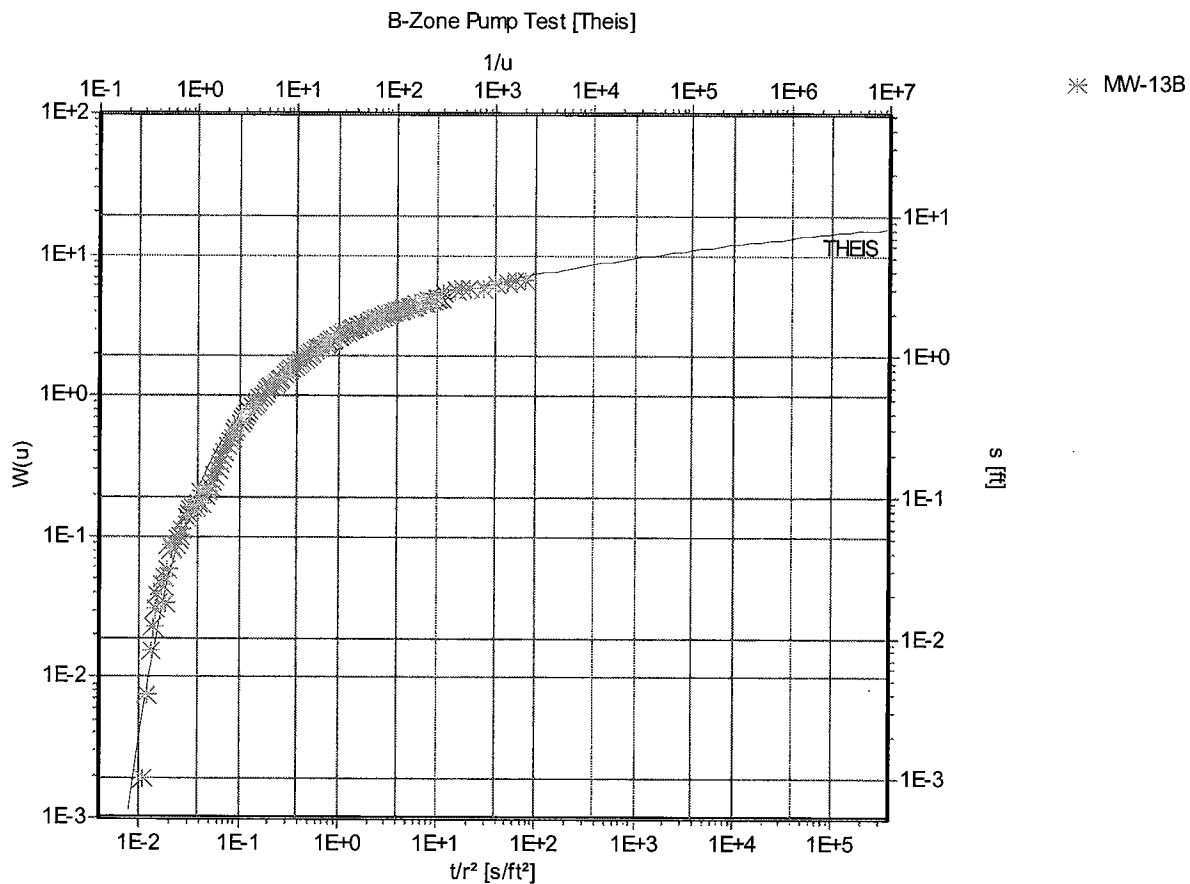
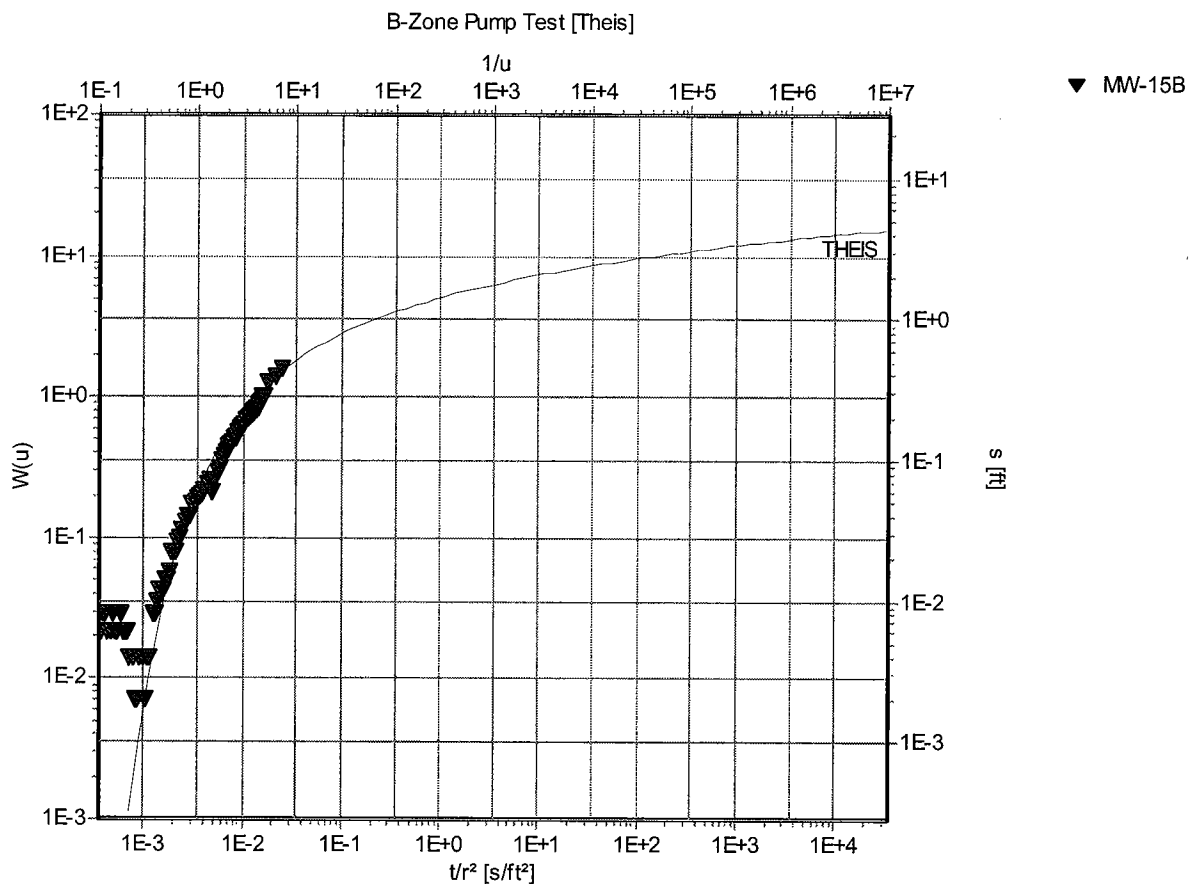Pumping Test: **B-Zone Pump Test**

Analysis Method: **Theis**

Analysis Results:	Transmissivity:	7.85E+0 [cm²/s]	Conductivity:	8.59E-3 [cm/s]
	Storativity:	1.31E-3		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

	Evaluated by:	RLS
	Evaluation Date:	4/26/2006

Pumping Test Analysis Report
Project: Hookston Aquifer Testing
Number: 0020557.10
Client:

B-Zone Pump Test [Theis]

+ MW8B

Pumping Test: **B-Zone Pump Test**

Analysis Method: **Theis**

Analysis Results:	Transmissivity:	9.88E+0 [cm²/s]	Conductivity:	1.08E-2 [cm/s]
	Storativity:	2.07E-4		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006

ERM-West, Inc.

1777 Botelho Drive, Suite 260

Walnut Creek, CA 94596

925-946-0455
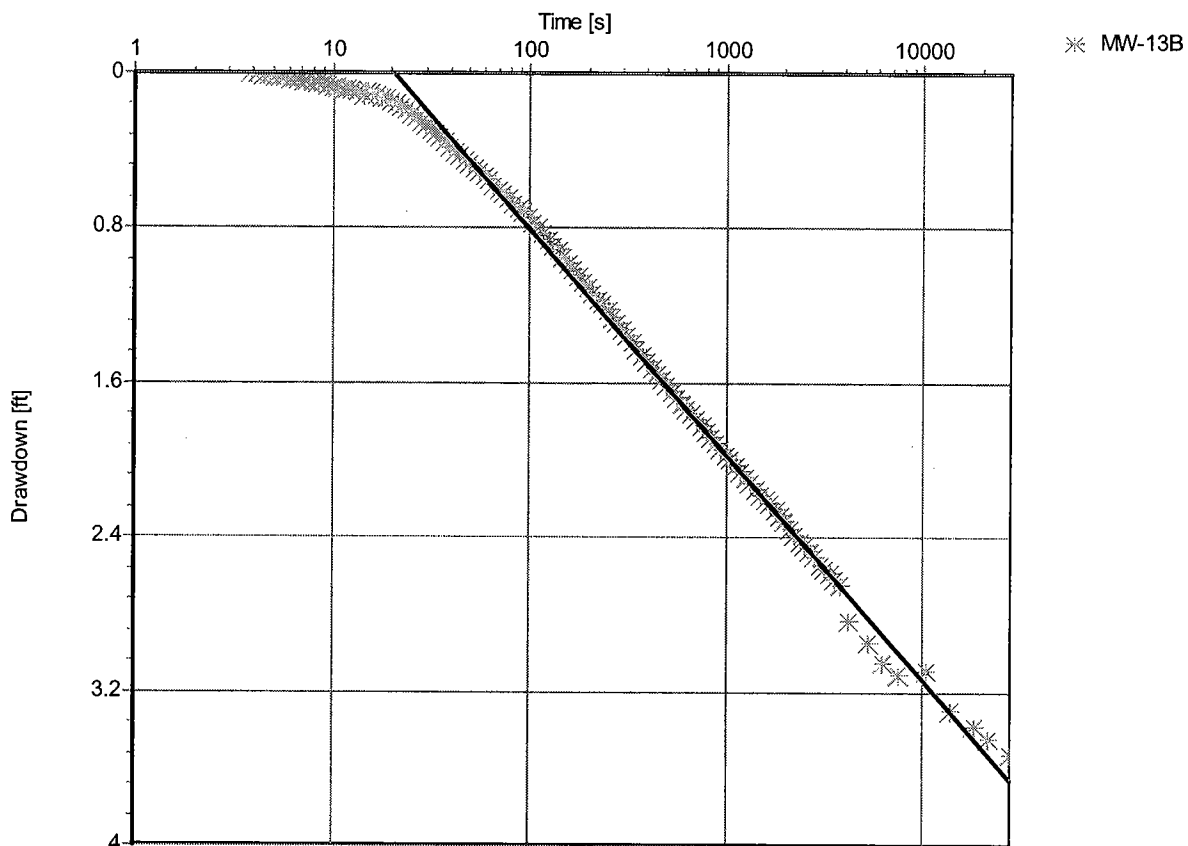
Pumping Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

B-Zone Pump Test [Theis]

▼ MW-15B

Pumping Test: **B-Zone Pump Test**

Analysis Method: **Theis**

Analysis Results:	Transmissivity:	1.46E+1 [cm²/s]	Conductivity:	1.60E-2 [cm/s]
	Storativity:	2.22E-4		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

	Evaluated by:	RLS
	Evaluation Date:	4/26/2006

Pumping Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

B-Zone Pump Test [Cooper-Jacob Time-Draw dow n]

Pumping Test:	**B-Zone Pump Test**
Analysis Method:	**Cooper-Jacob Time-Drawdown**

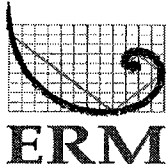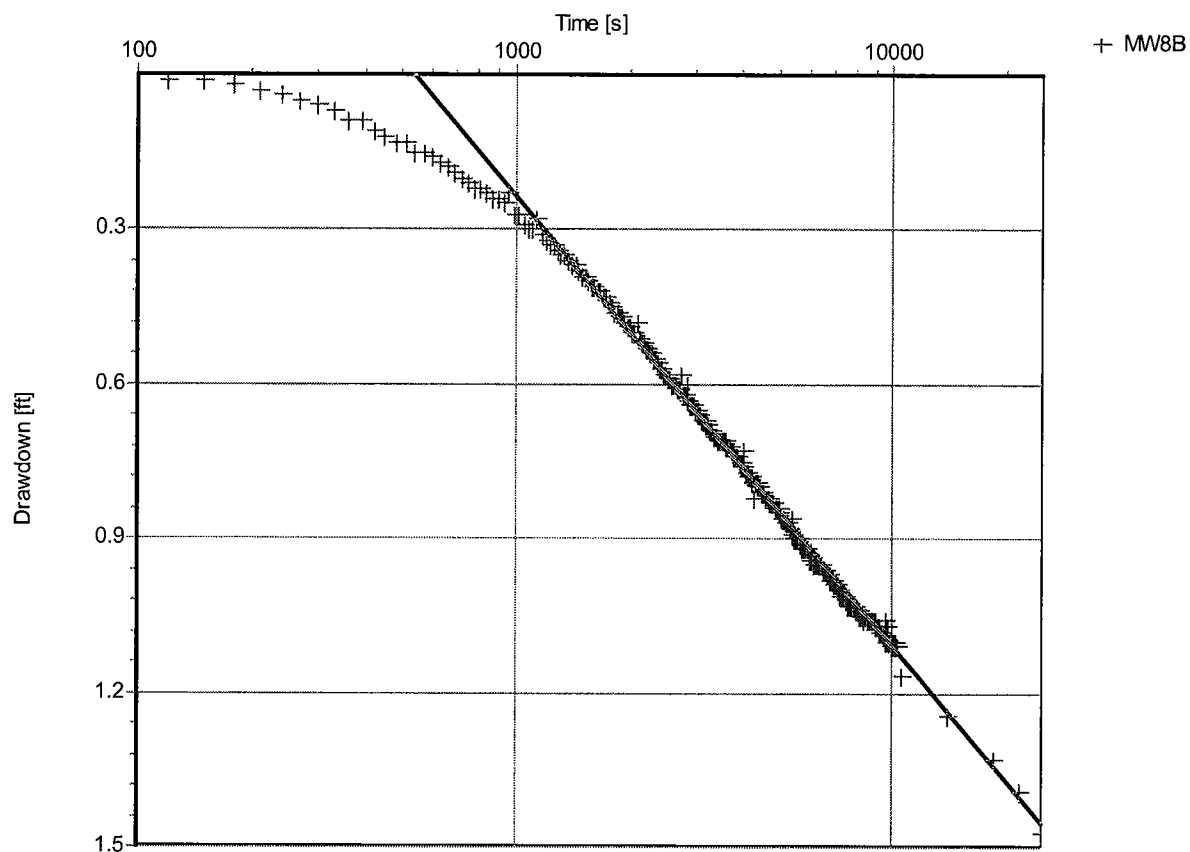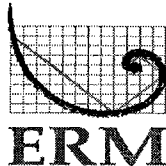| Analysis Results:	Transmissivity:	8.12E+0 [cm²/s]	Conductivity:	8.88E-3 [cm/s]

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006

B-Zone Pump Test [Cooper-Jacob Time-Draw dow n]

Time [s]

+ MW8B

Drawdown [ft]

Pumping Test:	**B-Zone Pump Test**
Analysis Method:	**Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	1.08E+1 [cm²/s]	Conductivity:	1.18E-2 [cm/s]
	Storativity:	1.92E-4		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006

Pumping Test Analysis Report	
Project: Hookston Aquifer Testing	
Number: 0020557.10	
Client:	

B-Zone Pump Test [Cooper-Jacob Time-Draw dow n]

▼ MW-15B

Pumping Test: **B-Zone Pump Test**

Analysis Method: **Cooper-Jacob Time-Drawdown**

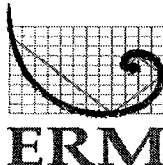| Analysis Results:	Transmissivity:	1.96E+1 [cm²/s]	Conductivity:	2.15E-2 [cm/s]

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006

ERM-West, Inc.	Pumping Test Analysis Report
1777 Botelho Drive, Suite 260	Project: Hookston Aquifer Testing
Walnut Creek, CA 94596	Number: 0020557.10
925-946-0455	Client:

B-Zone Pump Test [Cooper-Jacob Distance-Draw down]

Pumping Test: **B-Zone Pump Test**

Analysis Method: **Cooper-Jacob Distance-Drawdown**

Analysis Results:

Transmissivity:	2.51E+1 [cm²/s]	Conductivity:	2.75E-2 [cm/s]
Storativity:	9.44E-5		

Test parameters:

Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
Casing radius:	0.333 [ft]	Confined Aquifer	
Screen length:	30 [ft]		
Boring radius:	0.8333 [ft]		
Discharge Rate:	25 [U.S. gal/min]		
Calculation Time:	1000 [s]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006
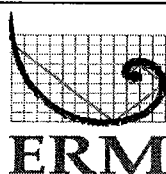
Pumping Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

B-Zone Pump Test [Cooper-Jacob Distance-Drawdown]

Legend:
+ MW8B
※ MW-13B
▼ MW-15B
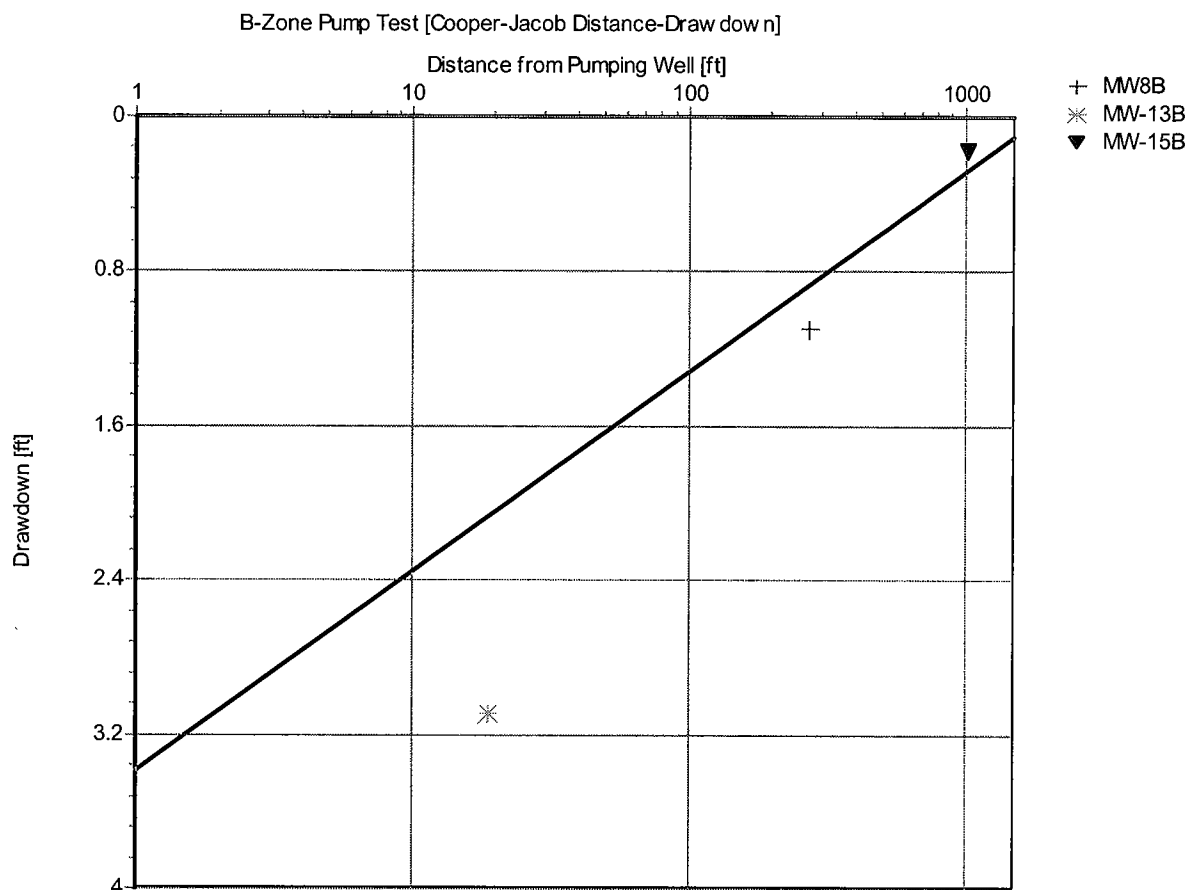
Pumping Test:	**B-Zone Pump Test**
Analysis Method:	**Cooper-Jacob Distance-Drawdown**

Analysis Results:	Transmissivity:	1.83E+1 [cm²/s]	Conductivity:	2.00E-2 [cm/s]
	Storativity:	1.22E-4		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		
	Calculation Time:	10000 [s]		

Comments:

Evaluated by:	RLS
Evaluation Date:	4/26/2006

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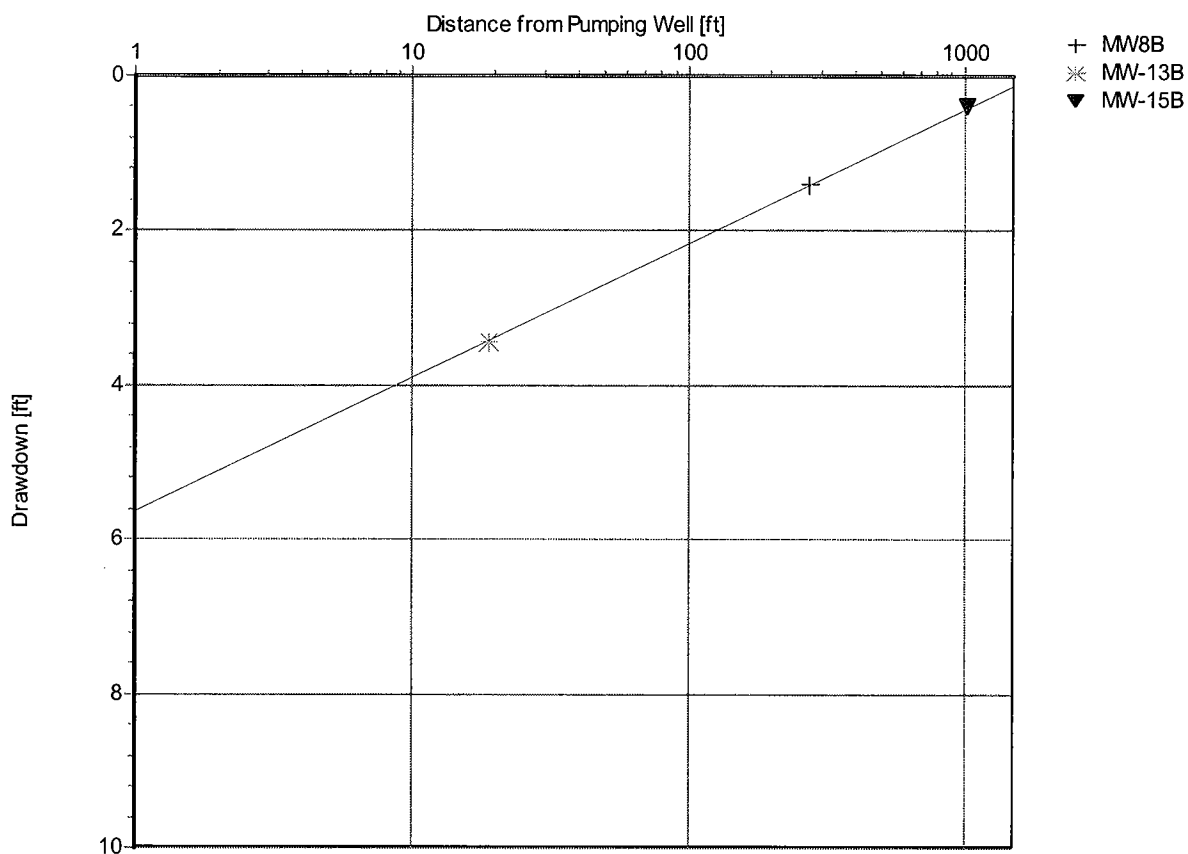
Walnut Creek, CA 94596

ERM 925-946-0455

Pumping Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

B-Zone Pump Test [Cooper-Jacob Distance-Draw dow n]

Distance from Pumping Well [ft]

Drawdown [ft]

Legend:
+ MW8B
※ MW-13B
▼ MW-15B

Pumping Test: **B-Zone Pump Test**

Analysis Method: **Cooper-Jacob Distance-Drawdown**

Analysis Results:	Transmissivity:	1.09E+1 [cm²/s]	Conductivity:	1.20E-2 [cm/s]
	Storativity:	1.70E-4		

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	30 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		
	Calculation Time:	20000 [s]		

Comments:
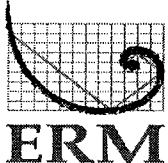
Evaluated by:

Evaluation Date: 4/26/2006

ERM-West, Inc.

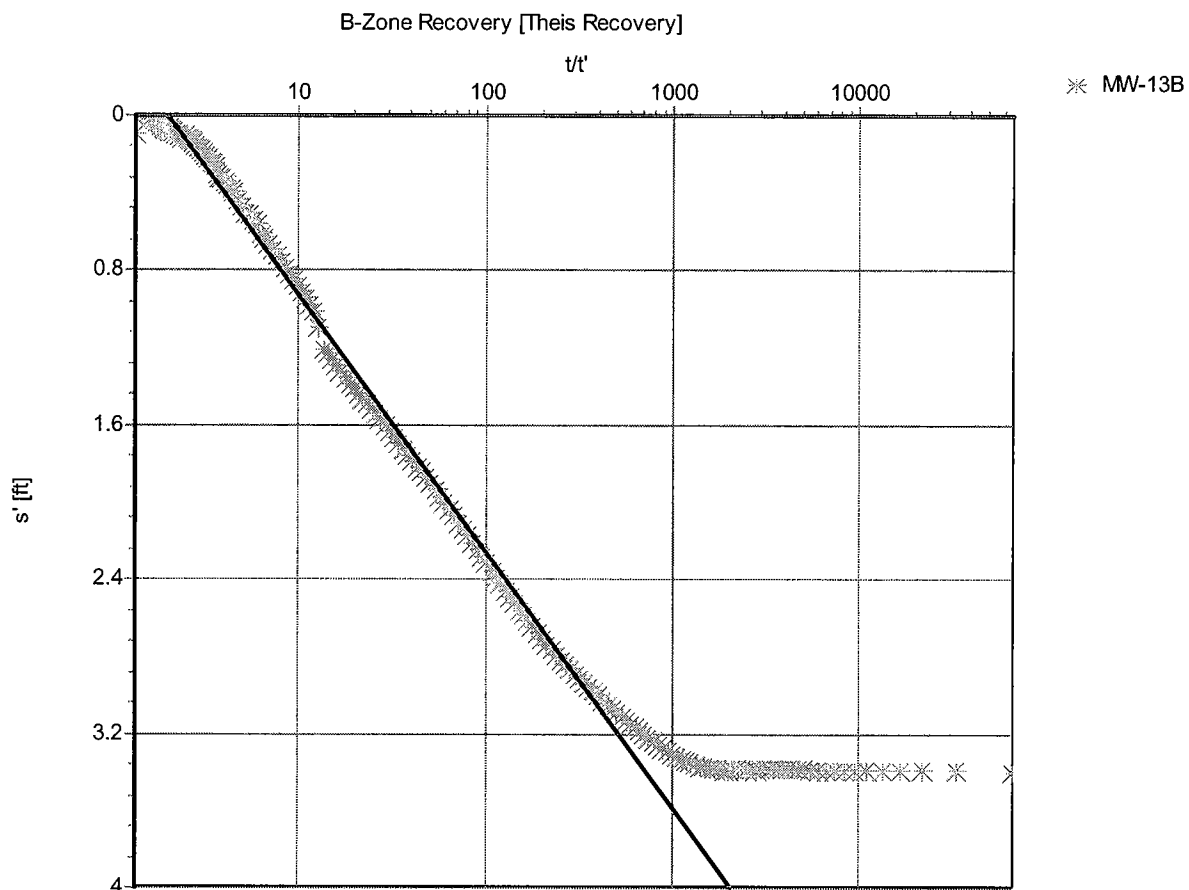1777 Botelho Drive, Suite 260

Walnut Creek, CA 94596

ERM 925-946-0455

Pumping Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

B-Zone Recovery [Theis Recovery]

⁂ MW-13B

Pumping Test: **B-Zone Recovery**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	7.13E+0 [cm²/s]	Conductivity:	1.56E-2 [cm/s]

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	15 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		
	Pumping Time	20000 [s]		

Comments:

Evaluated by:

Evaluation Date: 4/26/2006

ERM-West, Inc.
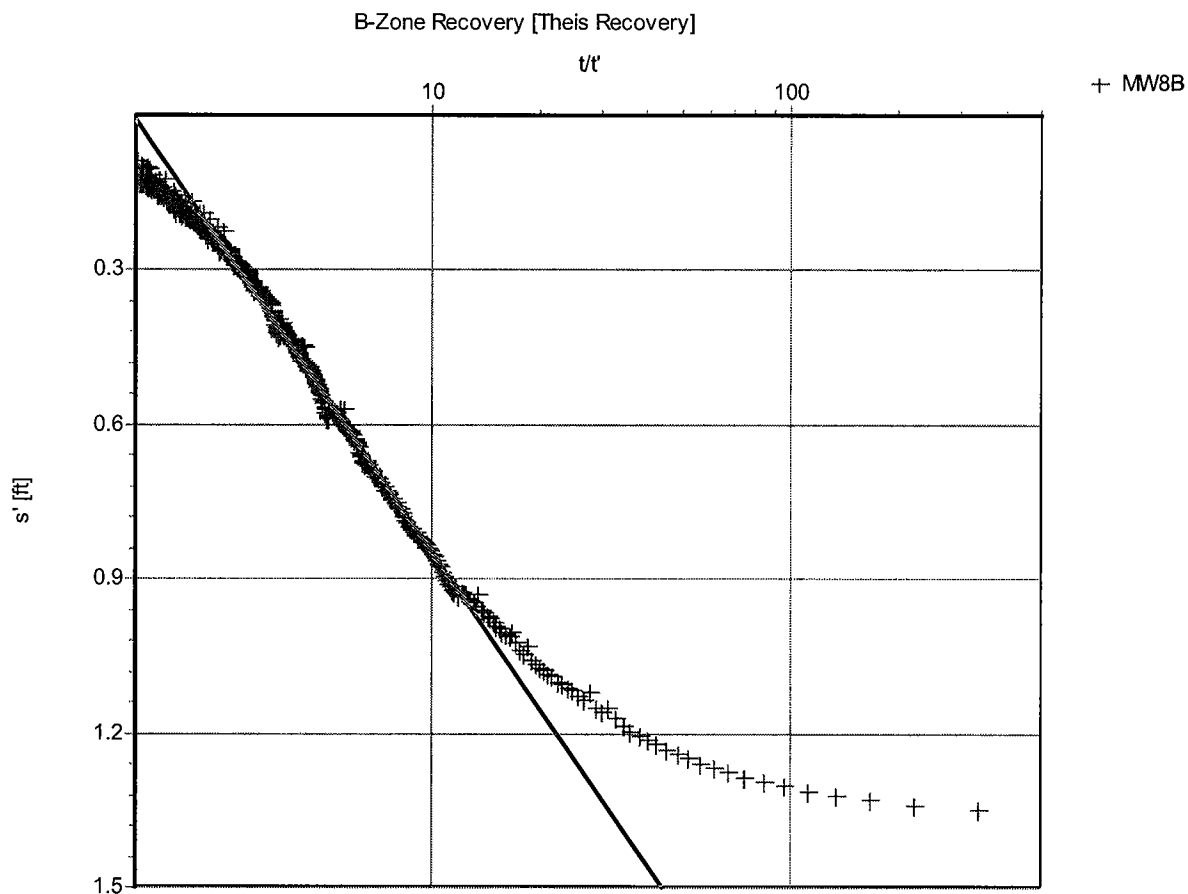1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

| **Pumping Test Analysis Report** |
| Project: Hookston Aquifer Testing |
| Number: 0020557.10 |
| Client: |

B-Zone Recovery [Theis Recovery]

Pumping Test: **B-Zone Recovery**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	9.31E+0 [cm²/s]	Conductivity:	2.04E-2 [cm/s]

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	15 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		
	Pumping Time	20000 [s]		

Comments:

Evaluated by: RLS

Evaluation Date: 4/26/2006

ERM-West, Inc.

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Walnut Creek, CA 94596

ERM 925-946-0455

Pumping Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

B-Zone Recovery [Theis Recovery]

t/t'

10   ▼ MW-15B

Pumping Test: **B-Zone Recovery**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	2.47E+1 [cm²/s]	Conductivity:	5.41E-2 [cm/s]

Test parameters:	Pumping Well:	TW-1	Aquifer Thickness:	15 [ft]
	Casing radius:	0.333 [ft]	Confined Aquifer	
	Screen length:	30 [ft]		
	Boring radius:	0.8333 [ft]		
	Discharge Rate:	25 [U.S. gal/min]		
	Pumping Time	20000 [s]		

Comments:

Evaluated by:

Evaluation Date: 4/26/2006

ERM-West, Inc.
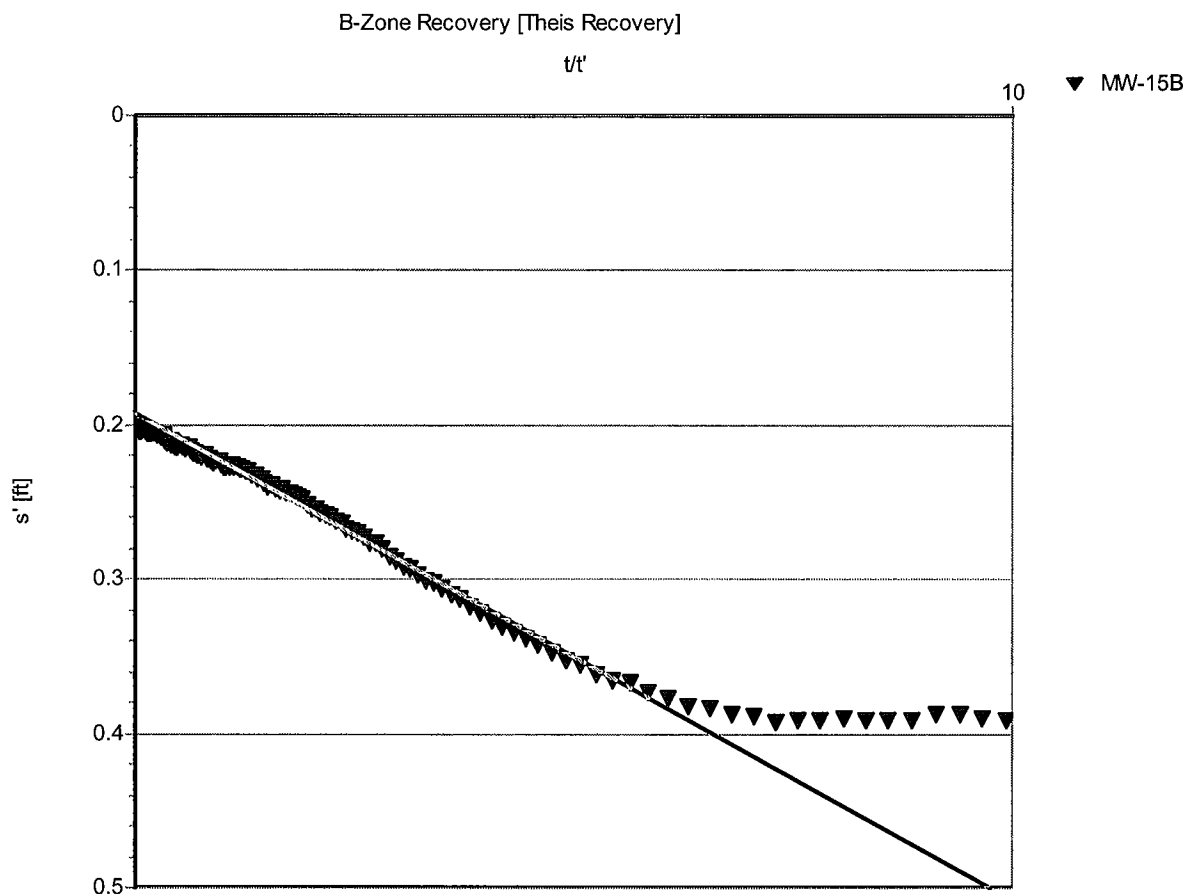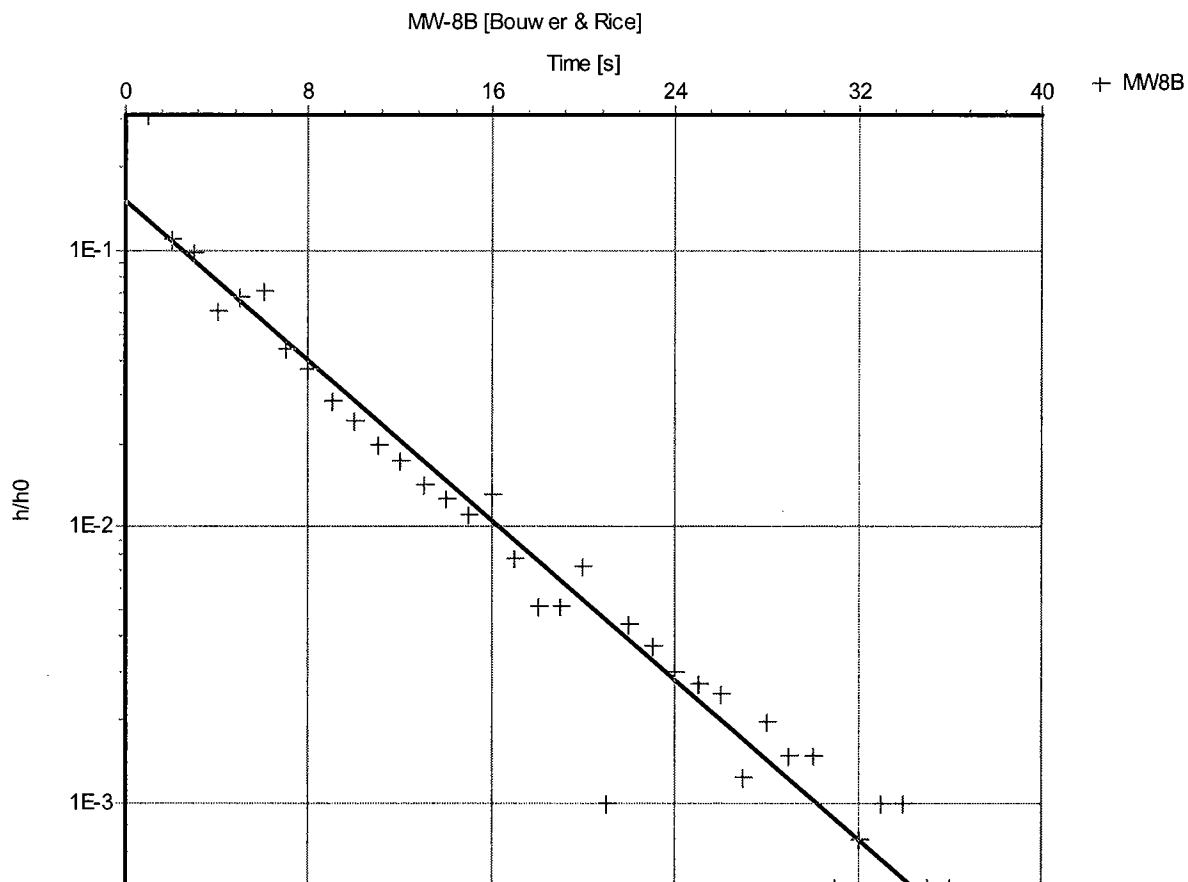1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
ERM 925-946-0455

Slug Test Analysis Report	
Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

MW-8B [Bouw er & Rice]

Slug Test: **MW-8B**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 9.55E-3 [cm/s]

Test parameters: Test Well: MW8B   Aquifer Thickness: 9 [ft]

                    Casing radius: 0.1666 [ft]   Gravel Pack Porosity (%)   25

                    Screen length: 15 [ft]

                    Boring radius: 0.666 [ft]
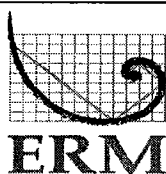
                    r(eff):   0.363 [ft]

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

ERM-West, Inc.
1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455
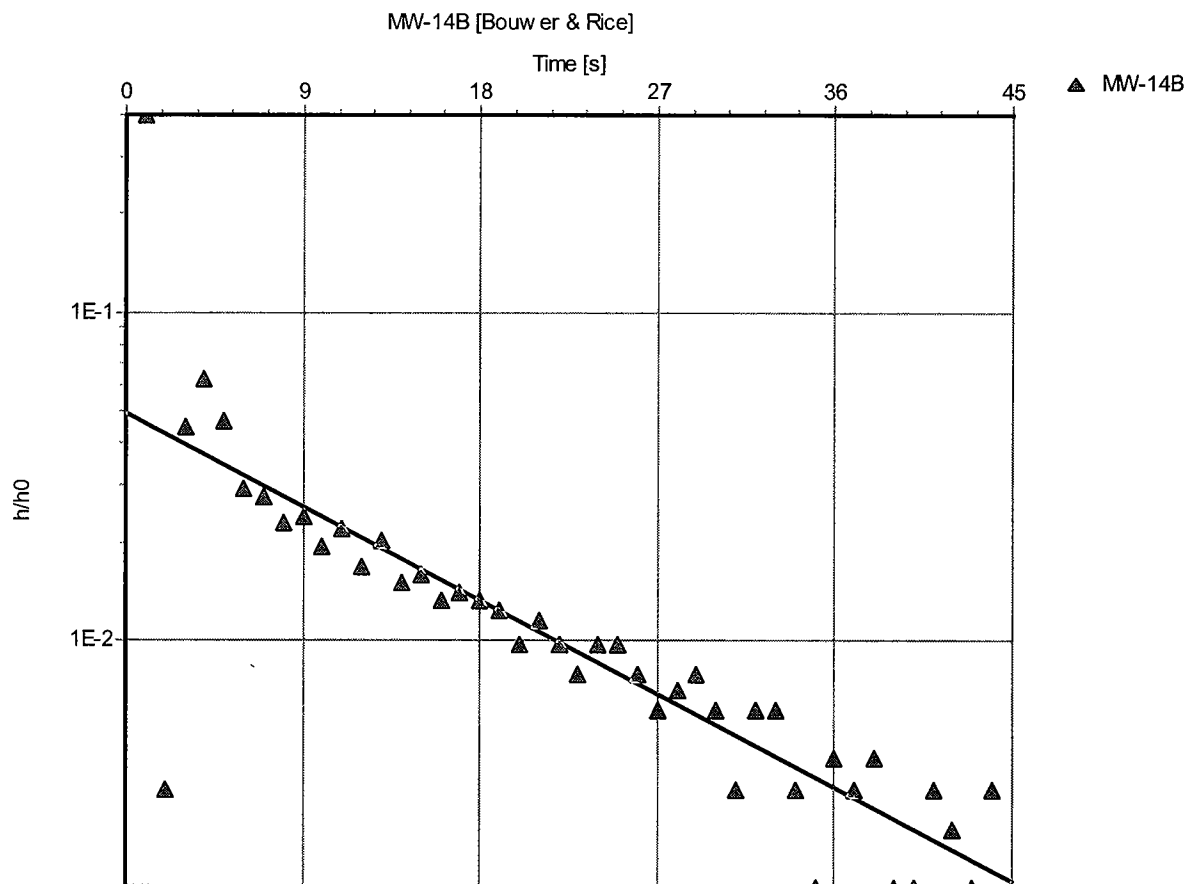
Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

MW-14B [Bouwer & Rice]

Slug Test: **MW-14B**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity: 5.87E-3 [cm/s]

Test parameters:	Test Well:	MW-14B	Aquifer Thickness:	8 [ft]
	Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
	Screen length:	10 [ft]		
	Boring radius:	0.666 [ft]		
	r(eff):	0.363 [ft]		

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:

MW-15B [Bouwer & Rice]

Time [s]

▼ MW-15B

Slug Test: **MW-15B**

Analysis Method: **Bouwer & Rice**

Analysis Results:

Conductivity:	1.59E-3 [cm/s]

Test parameters:

Test Well:	MW-15B		Aquifer Thickness:	10 [ft]
Casing radius:	0.1666 [ft]		Gravel Pack Porosity (%)	25
Screen length:	10 [ft]			
Boring radius:	0.666 [ft]			
r(eff):	0.363 [ft]			

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

ERM-West, Inc.
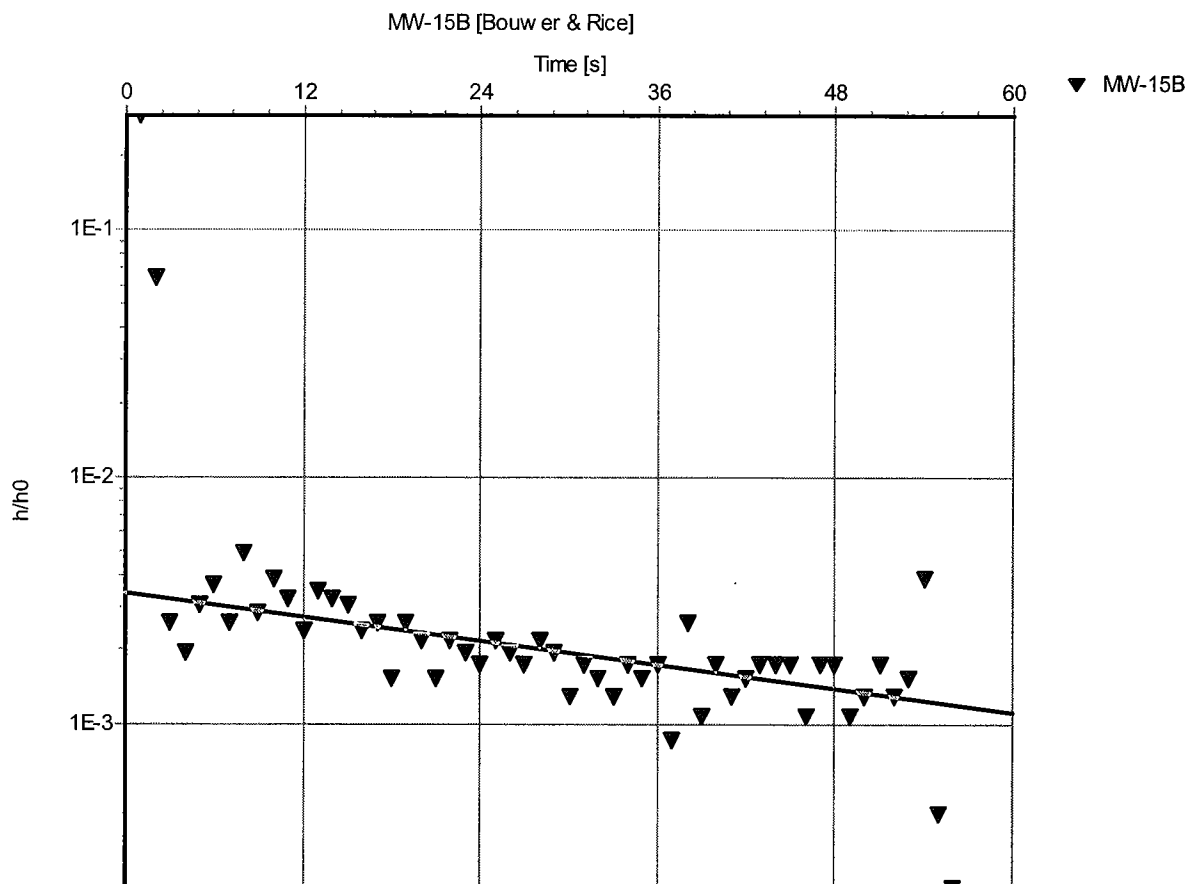1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

Slug Test Analysis Report

Project:	Hookston Aquifer Testing
Number:	0020557.10
Client:	

ERM

MW-16B [Bouw er & Rice]

Time [s]

h/h0
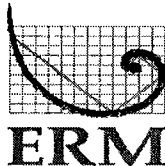
▲ MW-16B

Slug Test:	**MW-16B**
Analysis Method:	**Bouwer & Rice**

Analysis Results:

	Conductivity:	7.38E-3 [cm/s]

Test parameters:

Test Well:	MW-16B		Aquifer Thickness:	9 [ft]
Casing radius:	0.1666 [ft]		Gravel Pack Porosity (%)	25
Screen length:	10 [ft]			
Boring radius:	0.666 [ft]			
r(eff):	0.363 [ft]			

Comments:

Evaluated by:

Evaluation Date: 5/1/2006

ERM-West, Inc.

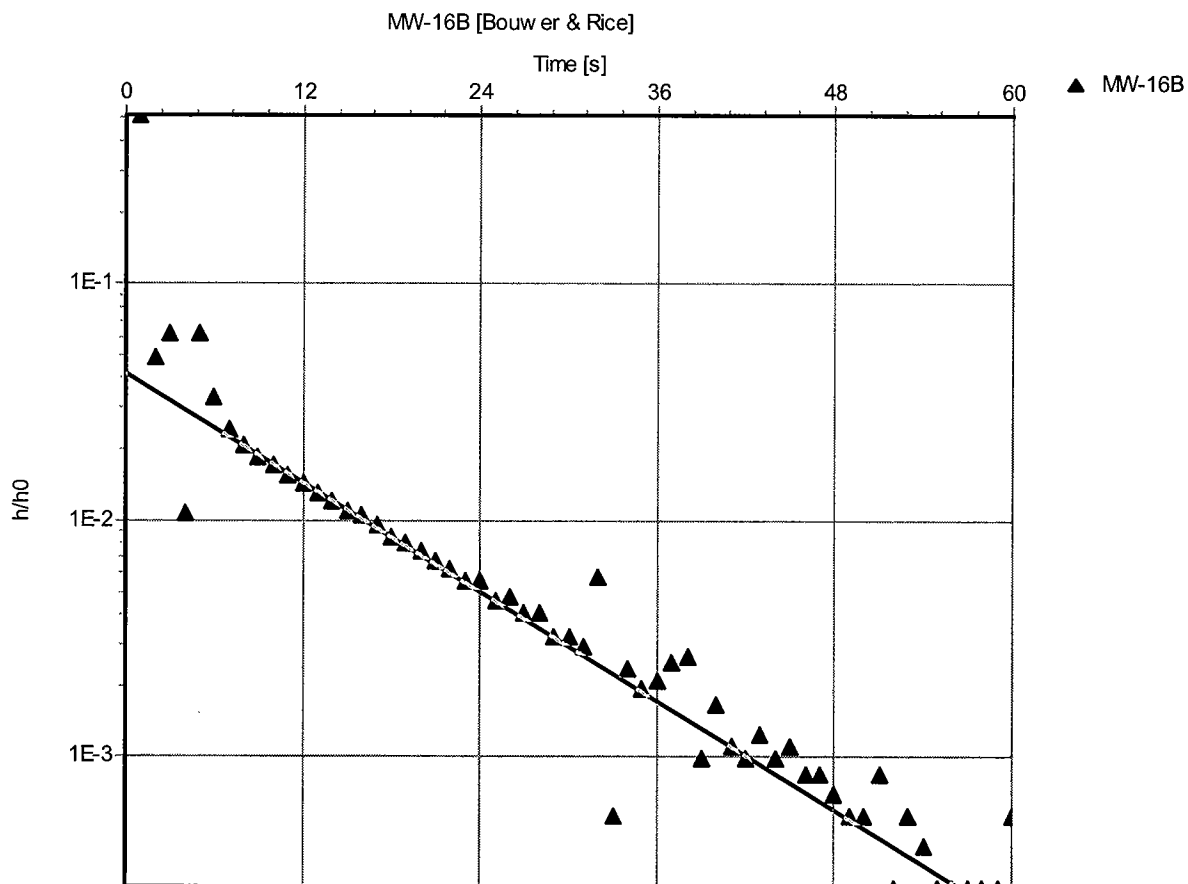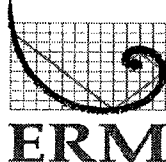1777 Botelho Drive, Suite 260
Walnut Creek, CA 94596
925-946-0455

Slug Test Analysis Report

Project: Hookston Aquifer Testing

Number: 0020557.10

Client:
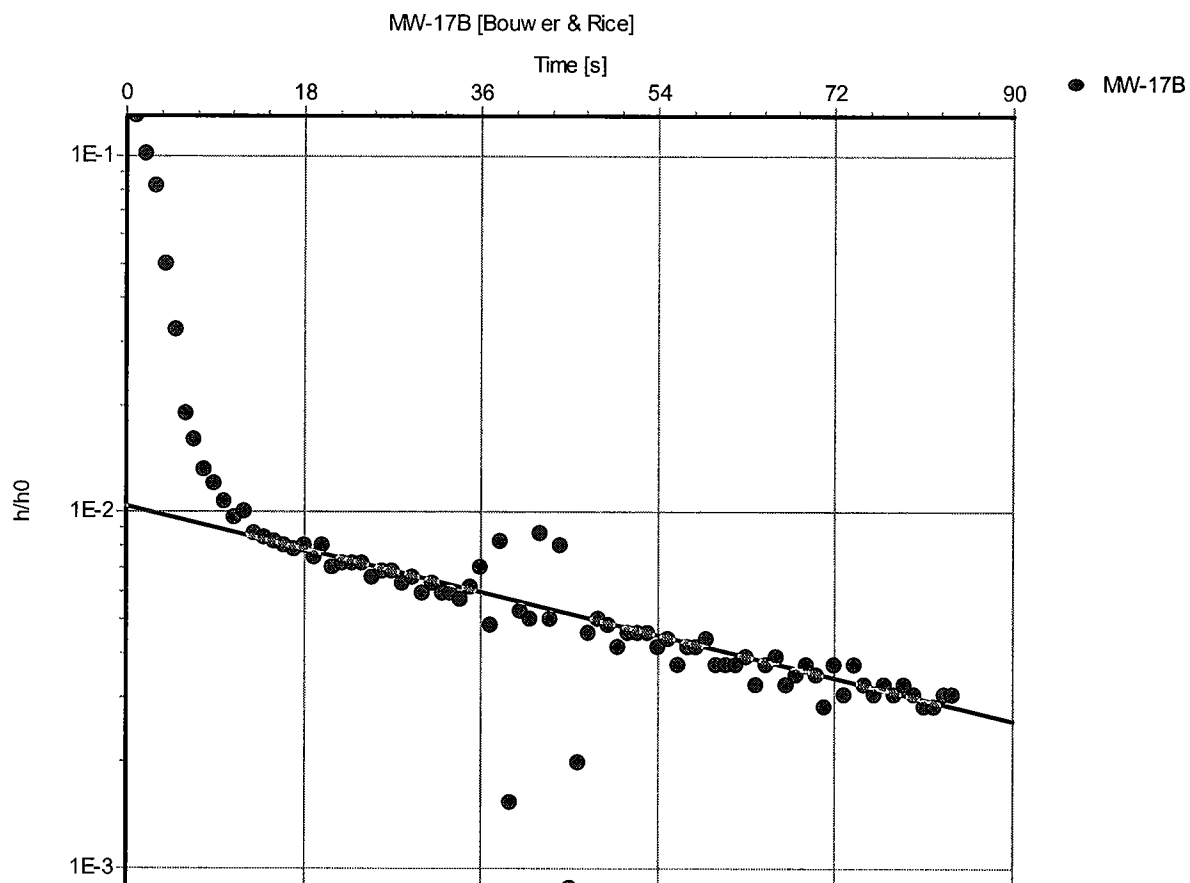
MW-17B [Bouwer & Rice]

Slug Test:	**MW-17B**
Analysis Method:	**Bouwer & Rice**

Analysis Results:		Conductivity:	1.33E-3 [cm/s]

Test parameters:	Test Well:	MW-17B	Aquifer Thickness:	10 [ft]
	Casing radius:	0.1666 [ft]	Gravel Pack Porosity (%)	25
	Screen length:	10 [ft]		
	Boring radius:	0.666 [ft]		
	r(eff):	0.363 [ft]		

Comments:

Appendix H
Risk-Based Cleanup Concentrations for
Chemicals of Concern

Risk-Based Concentrations for Chemicals of Interest

(1) Risk-Based Concentrations for Arsenic in On-site Soils

(2) Risk-Based Concentrations for Chemicals in Indoor Air

(3) Risk-Based Concentrations for Chemicals in Groundwater Used for Irrigation

(4) Risk-Based Concentrations for Chemicals in Groundwater Used to Fill Backyard Swimming Pools

Summary of Risk-Based Concentrations for Soil, Indoor Air, and Groundwater

Medium	Receptor	Exposure Scenario	Chemical of Interest	*Cancer Risk-Based Concentration	**Noncancer Risk-Based Concentration
On-site Soil	Commercial/ Industrial Worker	Direct contact with on-site soil	Arsenic	4.3 mg/kg (target risk = 10^{-5})	440 mg/kg
	Construction Worker	Direct contact with on-site soil	Arsenic	31.0 mg/kg (target risk = 10^{-5})	912 mg/kg
Off-site Indoor Air	Residents	Inhalation of indoor air	Trichloroethylene cis-1,2-Dichloroethylene trans-1,2-Dichloroethylene 1,1-Dichloroethylene Vinyl chloride	0.96 ug/m^3 NC NC NC 0.025 ug/m^3	69 ug/m^3 63 ug/m^3 125 ug/m^3 357 ug/m^3 181 ug/m^3
Off-site Groundwater	Residents	Inhalation of chemicals released from groundwater during irrigation	Trichloroethylene cis-1,2-Dichloroethylene trans-1,2-Dichloroethylene 1,1-Dichloroethylene Vinyl chloride	1890 ug/L NC NC NC 49.2 ug/L	33,900 ug/L 30,800 ug/L 61,700 ug/L 176,000 ug/L 89,300 ug/L
		Swimming contact with groundwater used to fill a backyard pool	Trichloroethylene cis-1,2-Dichloroethylene trans-1,2-Dichloroethylene 1,1-Dichloroethylene Vinyl chloride	1105 ug/L NC NC NC 121 ug/L	815 ug/L 42,700 ug/L 85,500 ug/L 155,000 ug/L 19,600 ug/L

* Target risk = 1 x 10^{-6} unless noted
**Total Hazard Quotient = 1
NC – not carcinogenic

-

(1) Risk-Based Concentrations for Arsenic in On-site Soils

Risk-based concentrations for arsenic in soil were calculated for the on-site commercial/industrial worker (C/I worker) and on-site construction worker. Exposure assumptions, toxicity factors, and equations used to calculate risk-based concentrations for arsenic in soil are presented below.

Soil Exposure Parameters and Toxicity Values

Symbol	Definition (units)	Values	References (refer to USEPA 2004 for full references)
CSF_o	Cancer slope factor oral (mg/kg-d)$^{-1}$	--	Arsenic = 9.46
CSF_i	Cancer slope factor inhaled (mg/kg-d)$^{-1}$	--	Arsenic = 12.0
RfD_o	Reference dose oral (mg/kg-d)	--	Arsenic = 3E-04
RfD_i	Reference dose inhaled (mg/kg-d)	--	Arsenic = 8.57E-06
TR	Target cancer risk	10^{-5}	Feasibility Study
THQ	Target hazard quotient	1	Feasibility Study
BW_a	Body weight, adult (kg)	70	RAGS (Part A), USEPA 1989 (EPA/540/1-89/002) Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
AT_c	Average time – carcinogens (days)	25,550	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
AT_n	Average time – noncarcinogens (days)	ED*365	USEPA 2004
SA_{aw}	Exposed surface area, C/I worker (cm^2/day)	3,300	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005))
$SA_{ac/tw}$	Exposed surface area, construction worker (cm^2/day)	5,800	Exposure Factors, USEPA 1997 (EPA/600/P-95/002Fa)
AF_{aw}	Adherence factor, C/I worker (mg/cm^2)	0.20	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
AF_{ctw}	Adherence factor, construction worker (mg/cm^2)	0.51	SFRWQCB, 2005
ABS	Skin absorption (unitless)	--	Arsenic = 0.03
IRA_a	Inhalation rate – adult (m^3/day)	20	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
IRS_o	Soil ingestion – occupational (mg/day)	50	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
*IRS_{ctw}	Soil ingestion – construction/trench worker (mg/day)	330	USEPA 2001
*EF_{ctw}	Exposure frequency – construction/trench worker (d/y)	20	SFRWQCB, 2005
ED_o	Exposure duration – occupational (years)	25	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
*ED_{ctw}	Exposure duration – construction/trench worker (years)	7	SFRWQCB, 2005
$PEF_{res/oc}$	Particulate emission factor (m^3/kg) - residential/occupational exposure scenarios	1.32E+09	Soil Screening Guidance (USEPA 1996a)
*PEF_{ctw}	Particulate emission factor (m^3/kg) - construction/trench worker exposure scenarios	1.44E+06	SFRWQCB, 2005.

-

<u>Equations Used to Calculate Risk-Based Soil Concentrations for Arsenic</u>

Cancer Risk

$$C(mg/kg) = \frac{TR \times BW \times AT_c}{EF \times ED \left[\left(\dfrac{IRS \times CSF}{10^6 mg/kg} \right) + \left(\dfrac{SA \times AF \times ABS \times CSF_o}{10^6 mg/kg} \right) + \left(\dfrac{IRA_a \times CSF_i}{PEF} \right) \right]}$$

Noncancer Risk

$$C(mg/kg) = \frac{THQ \times BW_a \times AT_n}{EF \times ED \left[\left(\dfrac{1}{RfD_o} \times \dfrac{IRS}{10^6 mg/kg} \right) + \left(\dfrac{1}{RfD_o} \times \dfrac{SA \times AF \times ABS}{10^6 mg/kg} \right) + \left(\dfrac{1}{RfD_i} \times \dfrac{IRA}{PEF} \right) \right]}$$

(2) Risk-Based Concentrations for Chemicals in Indoor Air

Risk-based concentrations of for chemicals in indoor air were calculated for off-site residents. Exposure assumptions, toxicity factors, and equations are presented below.

Resident Exposure Parameters and Toxicity Values-Indoor Air Exposure

Symbol	Definition (units)	Value	References
CSF_i	Cancer slope factor inhaled (mg/kg-d)$^{-1}$	Trichloroethylene – 0.007 cis-1,2-Dichloroethylene – not applicable trans-1,2-Dichloroethylene – not applicable 1,1-Dichloroethylene – not applicable Vinyl chloride – 0.27	CTEH, 2006
RfD_i	Reference dose inhaled (mg/kg-d)	Trichloroethylene – 0.011 cis-1,2-Dichloroethylene – not detected trans-1,2-Dichloroethylene – not detected 1,1-Dichloroethylene – 0.057 Vinyl chloride – 0.029	CTEH, 2006
TR	Target cancer risk	10^{-6}	Feasibility Study
THQ	Target hazard quotient	1	Feasibility Study
BW	Body weight, adult (kg) Body weight, child (kg)	70 15	RAGS (Part A), USEPA 1989 (EPA/540/1-89/002) Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
AT_c	Average time – carcinogens (days)	25,550	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
AT_n	Average time – noncarcinogens (days)	ED*365	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
IRA_a	Inhalation rate – adult (m^3/day)	20	CTEH, 2006
IRA_c	Inhalation rate – child (m^3/day)	10	CTEH, 2006
EF	Exposure frequency (days/year)	350	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
ED_a ED_c	Exposure duration – adult (years) Exposure duration – child (years)	24 6	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)

Equations Used to Calculate Risk-Based Indoor Air Concentrations for Residents

Cancer Risk

$$C(ug/m^3) = \frac{TR \times AT_c \times 1000 \, ug/mg}{EF \times \left[\left(\frac{ED_a \times IRA_a}{BW_a}\right) + \left(\frac{ED_c \times IRA_c}{BW_c}\right)\right] \times CSF_i}$$

Noncancer Risk

$$C(ug/m^3) = \frac{THQ \times BW_c \times AT_n \times 1000 \, ug/mg}{EF \times ED_c \times IRA_c \times \left(\frac{1}{RfD_i}\right)}$$

(3) Risk-Based Concentrations for Chemicals in Groundwater Used for Irrigation by Residents

Risk-based concentrations for chemicals in groundwater used as irrigation water by off-site residents were calculated using the exposure assumptions, toxicity factors, and equations are presented below.

Exposure Parameters and Toxicity Values- Irrigation Scenario

Symbol	Definition (units)	Value	References
CSF_i	Cancer slope factor inhaled $(mg/kg\text{-}d)^{-1}$	Trichloroethylene – 0.007 cis-1,2-Dichloroethylene – not applicable trans-1,2-Dichloroethylene – not applicable 1,1-Dichloroethylene – not applicable Vinyl chloride – 0.27	CTEH, 2006
RfD_i	Reference dose inhaled $(mg/kg\text{-}d)$	Trichloroethylene – 0.011 cis-1,2-Dichloroethylene – 0.01 trans-1,2-Dichloroethylene – 0.02 1,1-Dichloroethylene – 0.057 Vinyl chloride – 0.029	CTEH, 2006
TR	Target cancer risk	10^{-6}	Feasibility Study
THQ	Target hazard quotient	1	Feasibility Study
BW_a BW_c	Body weight, adult (kg) Body weight, child (kg)	70 15	RAGS (Part A), USEPA 1989 (EPA/540/1-89/002) Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
AT_c	Average time – carcinogens (days)	25,550	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
AT_n	Average time – noncarcinogens (days)	ED*365	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
VF_{irr}	Volatilization factor for irrigation scenario (L/m^3)	0.00845	See accompanying text for derivation
IRA_a	Inhalation rate – adult (m^3/day)	6.7	CTEH, 2006 (8 hours/day x 0.830 m^3/hour)
IRA_c	Inhalation rate – child (m^3/day)	3.3	CTEH, 2006 (8 hours/day x 0.415 m^3/hour)
EF	Exposure frequency (days/year)	63	See text for explanation
ED_a ED_c	Exposure duration – adult (years) Exposure duration – child (years)	24 6	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)

Discussion of Assumptions

The volatilization factor (VF_{irr}; L/m^3) used to estimate volatile emissions from irrigation water into air was derived based on several assumptions regarding the amount of water used for irrigation. Shallow ground water is assumed to be used to irrigate a yard. In the irrigation scenario, residents are assumed to water a residential lawn during the warmest weeks of the year (18 weeks). Volatile organic compounds are assumed to completely volatilize over an 8 hour period starting with the onset of irrigation. Residents are assumed to be exposed over the entire 8 hour volatilization period by inhaling the volatilizing VOCs. Such a scenario is likely to occur over nighttime hours when residents are at home and evaporation of the irrigation water is efficiently minimized.

The following assumptions were used to estimate VOC emissions from ground water used for irrigation.

Amount of ground water for irrigation
Conservatively, 7.62 cm (3 inches) of water per week are assumed to be needed for lawn irrigation weekly. According to Maddaus and Mayer ("Splash or Sprinkle? Comparing the Water Use of Swimming Pools and Irrigated Landscapes", undated), annual irrigation water use in arid climates (Boulder, Denver, San Diego, Phoenix, Tempe, Scottsdale, Walnut Valley, Las Virgenes, and Lompoc) ranged from 20.8 to 45.4 inches per year. Given the assumptions below (18 weeks of irrigation at 3 inches per week), annual irrigation with ground water is assumed to be 54 inches per year. This is a reasonably conservative estimate of the amount of ground water used to irrigate lawns in the Hookston Station area.

Number of weeks of lawn irrigation
Lawn irrigation is assumed to occur over 18 weeks (May 15 through September 15).

Number of irrigation events during the irrigation season
Lawns are assumed to be irrigated every other day for 18 weeks for 63 irrigation events per season or 3.5 events per week.

Area irrigated
The USEPA default residential exposure unit of 0.5 acre (20,235,000 cm^2) is assumed.

Total amount of water used per irrigation event
= (7.62 cm per week/3.5 irrigation events per week) x 20,235,000 cm^2 x 0.001 cm^3/L = 44,100 L

Rate of volatile emissions from ground water
VOCs are assumed to entirely volatilize within 8 hours.

Emission Calculations
The rate of volatilization of the VOCs from ground water used for irrigation is calculated according to the formula below:

VOC concentration in water (ug/L) x 44,100 L/irrigation event x (irrigation event/28,800 seconds) x (1/20,235,000 cm^2) x 0.000001 g/ug = Average rate of VOC flux (g/cm^2/sec)

Calculation of Air Concentrations
The residential VOC air concentrations of resulting from emission from using ground water for irrigation were calculated according to the formula:

$$C_{air} = \frac{\text{Rate of VOC flux} \times 10^4 \, cm^2/m^2}{Q/C \times 10^{-9} \, kg/ug}$$

-

where:

$C_{air}=$ Concentration in air, ug/m^3

Rate of VOC flux = calculated value, g/cm^2/sec
> If it is assumed that the VOC concentration in ground water is 1 mg/L, the calculated average rate of flux of VOCs during one irrigation event is calculated as

> 1 mg/L x 44,100 L/event x 1 event/day x (1 day/28,800 seconds per 8 hours) x (1/20,235,000 cm^2) x 0.001 g/mg = 7.57E-14 g/cm^2/sec

Q/C = inverse concentration factor for air dispersion for a 0.5 acre property in San Francisco (89.53 g/m^2-s per kg/m^3; USEPA, 1996)

Using the above equation and the assumptions discussed, the average air concentration after an irrigation event (assumed to be 8 hours) is 0.00845 mg/m^3. From this information, an irrigation specific volatilization factor can be calculated. This volatilization factor (VF$_{irr}$) is 0.00845 mg/m^3 per 1 mg/L or 0.00845 L/m^3. This value is used in calculating risk-based concentrations for the chemicals of potential concern in ground water used for irrigation.

Equations Used to Calculate Risk-Based Air Concentrations for Chemicals in Irrigation Water

Cancer Risk

$$C(ug/L) = \frac{TR \times AT_c \times 1000 \ ug/mg}{EF \times VF_{irr} \times \left[\left(\dfrac{IRA_c \times ED_c}{BW_c} \right) + \left(\dfrac{IRA_a \times ED_a}{BW_a} \right) \right] \times CSF_i}$$

Noncancer Risk

$$C(ug/L) = \frac{THQ \times RfD_i \times BW_c \times AT_n \times 1000 \ ug/mg}{EF \times VF_{irr} \times IRA_c \times ED_c}$$

(4) Risk-Based Concentrations for Chemicals in Groundwater Used to Fill Backyard Swimming Pools

Risk-based concentrations for chemicals in groundwater used to fill backyard swimming pools were calculated using the exposure assumptions, toxicity factors, and equations are presented below.

Exposure Parameters and Toxicity Values- Swimming Pool Scenario

Symbol	Description	Value	Reference/ Explanation
CSF_o	Cancer slope factor oral $(mg/kg\text{-}d)^{-1}$	Trichloroethylene – 0.013 cis-1,2-Dichloroethylene – not applicable trans-1,2-Dichloroethylene – not applicable 1,1-Dichloroethylene – not applicable Vinyl chloride – 0.27	CTEH, 2006
CSF_i	Cancer slope factor inhaled $(mg/kg\text{-}d)^{-1}$	Trichloroethylene – 0.007 cis-1,2-Dichloroethylene – not applicable trans-1,2-Dichloroethylene – not applicable 1,1-Dichloroethylene – not applicable Vinyl chloride – 0.27	CTEH, 2006
RfD_o	Reference dose oral (mg/kg-d)	Trichloroethylene – 0.0003 cis-1,2-Dichloroethylene – 0.01 trans-1,2-Dichloroethylene – 0.02 1,1-Dichloroethylene – 0.050 Vinyl chloride – 0.003	CTEH, 2006
RfD_i	Reference dose inhaled (mg/kg-d)	Trichloroethylene – 0.011 cis-1,2-Dichloroethylene – 0.01 trans-1,2-Dichloroethylene – 0.02 1,1-Dichloroethylene – 0.057 Vinyl chloride – 0.029	CTEH, 2006
AT_c	Averaging time for exposure; carcinogenic risk (days)	25,550	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
AT_n	Averaging time for exposure; noncarcinogenic risk (days)	4745	See text for explanation (13 years x 365 days per year)
BW	Body weight of child swimmer (kg)	41.5	USEPA 1997. Exposure Factors Handbook. Volume I – General Factors. Office of Health and Environmental Assessment; Average of male and females body weights from 5 through 17 years of age. Table 7-3.
$DA_{event\text{-}factor}$	Dermal uptake factor per swimming exposure $(L/mg/cm^2)$;	chemical-specific	See text for explanation
ED	Exposure duration, child swimmer (years)	13	Assumes swimming age from 5 years through 17 years of age
EF	Exposure frequency (days/yr)	108	See text for explanation
ET	Exposure time (hours)	1	USEPA, 2004

Exposure Parameters and Toxicity Values- Swimming Pool Scenario

Symbol	Description	Value	Reference/ Explanation
IR	Pool water ingestion rate (L/hr)	0.05	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
Pool loss factor	Factor used to adjust for loss of COPCs from pool water during season (unitless)	0.12	See text for explanation
SA	Skin surface area exposed during swimming (cm^2)	15,500	USEPA 1997. Exposure Factors Handbook. Volume I – General Factors. Office of Health and Environmental Assessment; Average body surface area of 5 to 18 year old male and female children; Tables 6-6 and 6-7
VF_{pool}	Volatilization factor for swimming pool scenario (L/m^3)	0.000977	See text for explanation
IRA	Inhalation rate for child swimmer (m^3/hr)	1.9	USEPA 1997. Exposure Factors Handbook. Volume I – General Factors. Office of Health and Environmental Assessment; Inhalation rate for heavy activity; Table 5-23

Cancer Risk

$$C(ug/L) = \frac{TR \times BW \times AT_c \times 1000\, ug/mg}{EF \times ED \times \left[\left(CSF_o \times DA_{event-factor} \times SA\right) + \left(CSF_i \times VF_{pool} \times IRA \times ET\right) + \left(CSF_o \times IR \times ET \times pool\ loss\ factor\right) \right]}$$

Noncancer Risk

$$C(ug/L) = \frac{THQ \times BW \times AT_{nc} \times 1000\ ug/mg}{EF \times ED \times \left[\left(\frac{DA_{event-factor} \times SA}{RfD_o} \right) + \left(\frac{VF_{pool} \times IRA \times ET}{RfD_i} \right) + \left(\frac{IR \times ET \times pool\ loss\ factor}{RfD_o} \right) \right]}$$

Discussion of Assumptions

A resident is assumed to fill a backyard pool with ground water containing the chemicals of interest (COIs). Exposure to the COIs in swimming pool water was assumed to occur via skin uptake during swimming, inhalation of volatilizing COIs, and ingestion of pool water.

Pool filling was assumed to occur once per season. Ground water was also assumed to be used to make up for losses resulting from evaporation and splashing.

The swimming season is assumed to last 18 weeks (approximately May 15 through September 15) or 126 days. During this time, a child is assumed to swim 6 days per week for 1 hour per day.

Concentration of the COIs in Swimming Pool Water
Due to their volatile nature, losses of the COIs via volatilization are accounted for by assuming an average rate of volatilization in which 50% of the chemical in the pool water will volatilize with 3.5

days. A typical backyard swimming pool is 30 feet long x 15 feet wide x 5 feet deep and would contain approximately 2250 cubic feet or 64,000 liters of water. Based on estimates for the Sacramento area prepared by the California Spa and Pool Industry Energy, Codes and Legislative Council (SPEC, 2002), a pool this size would require approximately 1000 L per day of water to replenish the pool (from water losses caused by evaporation, splashing, etc.).

Assuming that 1000 L per day of ground water are needed to replenish the pool, what is the seasonal average COI concentration in the over 126 days?

Assume 3.5 day half life (volatilization rate constant of 0.198 days^{-1})
Assume ground water concentration of COI is 1 mg/L
Assume pool contains 64,000 L of ground water
The first day after filling, the concentration of COI in pool after 24 hours of original filling
= 1 mg/L x $e^{(-0.198 \times 1)}$ = 0.82 mg/L at a volume of 63,000L

Add to this 1000 L containing 1 mg/L- what is the adjusted COI concentration in pool water?

(Concentration in pool x 63,000 L) + (1 mg/L x 1000 L) divided by 64,000 L

= 0.823 mg/L x $e^{(-0.198 \times 1)}$ = 0.675 mg/L at a volume of 63,000L

Add to this 1000 L containing 1 mg/L and the adjusted Day 2 COI concentration in pool water is calculated as (0.675 mg/L x 63,000 L) + (1 mg/L x 1000 L) divided by 64,000 L = 0.68 mg/L. This calculation was repeated for 30 days. It was determined that the concentration declines to 0.083 mg/L after about 30 days and remains fairly constant from Day 30 through Day 126. The average COI concentration in water over the 126 day swimming season is 0.12 mg/L. Based on these calculations, a swimming pool loss factor of 0.12 (0.12 mg/L divided by 1 mg/L) was calculated.

Calculation of Skin Uptake of Chemicals in Water
The equation used to calculate the dermally absorbed dose of the chemicals of concern in swimming pool water requires the calculation of a chemical-specific dermally absorbed dose through the skin. This value is called the DA_{event}.

For trichloroethylene (where t_{event} is less than or equal to t*), the DA_{event} is calculated using the following formula:

$$DA_{event} = 2 \times K_p \times C_{water} \times \text{swimming pool loss factor} \times \frac{L}{1000\,cm^3} \times \sqrt{\frac{6 \times tau \times t_{event}}{pi}}$$

For 1,1-dichloroethylene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene, and vinyl chloride (where t_{event} > t*), DA_{event} is calculated using the formula presented below:

$$DA_{event} = K_p \times C_{water} \times \text{swimming pool loss factor} \times \frac{L}{1000\,cm^3} \times \left[\frac{t_{event}}{1+B} + \left(2tau \times \frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

where:

DA_{event} = dermal dose absorbed through the skin per exposure event (mg/cm^2)

K_p = dermal permeability coefficient from Exhibit B-3 of USEPA, 2004 (cm/hr)

C_{water} = concentration in water (mg/L)

tau = Chemical-specific; from Exhibit B-3 of USEPA, 2004 (hours)

t_{event} = hours of exposure to water per event (1 hour)

pi = 3.14

The values of K_p, C_{water}, tau, and the calculated DA_{event} are presented in the table below. Values of DA_{event} were calculated using spreadsheets developed by the USEPA for use as described in USEPA, 2004 and as available from http://www.epa.gov/oswer/riskassessment/ragse/index.htm (accessed May 11, 2006)

Values for Kp, tau, t*, B, and DA$_{event-factor}$ for the Chemicals of Potential Concern

Chemical	K_p (cm/hr)	tau (hr)	t* (hr)	B	*DA_{event} (mg/cm^2)
Trichloroethylene	0.0120	0.580	1.39	0.051	2.94E-06
cis-1,2-Dichloroethylene	0.0077	0.370	0.89	0.029	1.61E-06
trans-1,2-Dichloroethylene	0.0077	0.370	0.89	0.029	1.61E-06
1,1-Dichloroethylene	0.0120	0.370	0.89	0.044	2.42E-06
Vinyl chloride	0.0056	0.240	0.57	0.017	9.86E-07

*Assumes 1 mg/L as starting concentration for COIs in swimming pool water

A DA_{event} factor for pool water is therefore the VOC-specific DA_{event} (in units of mg/cm^2) per 1 mg/L. The chemical-specific or DA_{event} factor is designated as $DA_{event-factor}$ and has the units of L/cm^2

Concentration of COIs in Air Above Swimming Pool

The air concentration of COIs above the pool was calculated to evaluate swimmer inhalation of VOCs over the swimming season. Given the assumed half-life of 3.5 days for VOC volatilization from pool water, the average emission rate of VOCs from a swimming pool containing 1 mg/L of VOC is calculated as

$$\frac{1 mg/L \ x \ 64,000L \ x \ 0.5}{86,400 \ seconds/day \ x \ 3.5 days} = 0.106 mg/s$$

To calculate a seasonal average emission rate, the emission rate is multiplied by swimming pool loss factor of 0.12 (calculated above) to give a seasonally adjusted emission rate of 0.0127 mg/s (0.106 mg/s x 0.12).

The box model was used to calculate air concentrations above the swimming pool at receptor height. The seasonally adjusted air concentration is 0.000977 mg/m^3 where

Seasonally adjusted emission rate = 0.0127 mg/s

Receptor height above water = 0.5 m

Side of pool perpendicular to the wind = 6.5 m (square root of pool area)

Windspeed = 4 m/s (http://ggweather.com/ca_climate/wind.htm)

$$\frac{0.0127 \ mg/s}{0.5 \ m \ x \ 6.5 \ m \ x \ 4 \ m/s} = 0.000977 \ mg/m^3$$

A seasonally adjusted swimming pool volatilization factor (VF_{pool}) can be calculated as 0.000977 mg/m^3 per 1 mg/L or 0.000977 L/m^3. This value is used in calculating risk-based concentrations for the chemicals of potential concern in ground water used for swimming pools.

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Appendix I
Ground Water Modeling

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LIST OF FIGURES

(immediately following text)

1.0   *INTRODUCTION*

Numerical ground water flow and solute transport models were developed for the Hookston Station to support the evaluation of remedial alternatives for volatile organic compounds (VOCs) in ground water. These models are designed to be representative of the general hydrogeologic conditions in the Hookston Station area. This appendix describes the design of the Hookston Station flow and transport models, the methods that were used to evaluate the remedial alternatives, and presents the results of the model simulations.

It should be noted that these computer models were constructed as a tool to compare the relative effectiveness (e.g., spatial impact and timeframes for VOC concentration reductions) of active remediation systems that are being evaluated within the Feasibility Study (FS). These are not fully calibrated ground water flow and solute transport models, and as such, the results of these modeling efforts should be considered estimates based upon the input parameters and assumptions that are described within this appendix. The modeling results cannot be relied upon for any purpose other than comparing the relative effectiveness of the remedial alternatives.

2.0   MODEL DESIGN

This section describes the principal design elements of the Hookston Station ground water flow and solute transport models. These design elements include the model codes that were selected to develop the models, the major assumptions of the model designs, the model grid and layering, the aquifer and transport properties assigned to the model grid, and the boundary conditions used in the flow and transport models.

The Hookston Station ground water flow and transport models were designed and constructed in accordance with the American Society for Testing and Materials (ASTM) guidelines for ground water modeling (ASTM 1996) and generally accepted industry practice (Anderson and Woessner 1992; Zheng and Bennett 1995). The ASTM guidelines were developed as part of a cooperative agreement between the United States Environmental Protection Agency (USEPA), the United States Geological Survey (USGS), and the United States Navy.

The Hookston Station ground water flow and transport models were constructed with Ground water Vistas™, a computer-aided design program for ground water modeling (Environmental Simulations Inc., 2004). Groundwater Vistas™ fully supports the model codes MODFLOW (McDonald and Harbaugh 1988), PATH3D (Zheng 1989), and MT3DMS (Zheng and Wang 1999), which were used to develop the Hookston Station ground water flow and transport models.

2.1   MODEL CODES

2.1.1   Ground Water Flow

The model code that was used to develop the Hookston Station ground water flow model is MODFLOW (McDonald and Harbaugh 1988), a three-dimensional, finite-difference ground water flow model developed by the USGS. MODFLOW was selected for development of the Hookston Station flow model because it is nonproprietary, well documented, and has been verified for a wide range of field problems (USEPA 1993). Numerous models based on this code have been published in technical journals (Anderson and Woessner 1992).

2.1.2 *Ground Water Flow Paths*

Ground water flow paths were simulated with the model code PATH3D. PATH3D is a three-dimensional, numerical particle tracking code for calculating ground water flow paths and travel times from the head solution output by MODFLOW. This model code was developed at the University of Wisconsin - Madison and the Wisconsin Geological and Natural History Survey (Zheng 1989). PATH3D is well documented and has been verified for a range of field problems.

2.1.3 *Solute Transport*

The Hookston Station solute transport model was developed with MT3DMS. MT3DMS is a three-dimensional, finite-difference solute transport model code developed by Zheng and Wang (1999) with funding from the United States Army Corps of Engineers Waterways Experiment Station. MT3DMS was selected for development of the Hookston Station transport model because it is nonproprietary, well documented, and is designed to be used with MODFLOW. Numerous models based on this and an earlier version of this code, MT3D (Zheng, 1990, 1993), have been published in technical journals (Zheng, and Bennett, 1995).

The MT3DMS transport simulations were solved using a total variation diminishing (TVD) method for solution of the advection term (Zheng and Wang 1999). The TVD method implemented in MT3DMS is a third-order TVD method with a universal flux limiter. This TVD method minimizes numerical dispersion and suppresses spurious oscillations in the model concentration solution while preserving sharp concentration fronts.

2.2 *GROUND WATER FLOW MODEL*

2.2.1 *Assumptions of Model Design*

The following simplifying assumptions were made in the design of the Hookston Station ground water flow model:

- The shallowest ground water flow system (A-Zone) receives no significant recharge by infiltration of precipitation and surface runoff.

- The A-, B-, and C- Zones have a uniform thickness and uniform values of hydraulic conductivity (i.e., values differ from one zone to another, but are uniform throughout a given zone).

- Vertical hydraulic conductivities are equal to one tenth of horizontal hydraulic conductivities.

- Vertical ground water flow between the A- and B-Zones, and the B- and C-Zones, is relatively insignificant.

- Vertical ground water flow between the C-Zone and underlying sediments is relatively insignificant.

- The simulated ground water extraction wells fully screen the aquifers in which they are completed.

2.2.2   *Model Grid*

The model grid constructed for the Hookston Station ground water flow model is a three-layer, 250-row by 200-column, uniformly spaced, finite-difference grid. The model grid is oriented north 55 degrees east, approximately parallel to the direction of ground water flow. The row and column spacing of the model grid is a uniform 25 feet. The overall model area spans 5,000 by 6,250 feet, which is just over 1 square mile (Figure I-1).

2.2.3   *Model Layers*

The ground water flow in the A-, B-, and C-Zones in the Hookston Station area are simulated in the model by three layers.

- Layer 1 represents the A-Zone;

- Layer 2 represents the B-Zone; and

- Layer 3 represents the C-Zone;

The bottom elevation of Layer 1, which represents the base of the A-Zone, is a uniform 40 feet above mean sea level (AMSL), an approximate depth of 30 feet below ground surface (bgs). The top elevation of this layer, which represents the water table, is calculated by MODFLOW during the model simulation period (McDonald and Harbaugh 1988).

The bottom elevation of Layer 2, which represents the base of the B-Zone, is a uniform 0 feet AMSL, an approximate depth of 70 feet bgs. The top elevation of this layer, which represents the base of the A-Zone, is 40 feet AMSL.

The bottom elevation of Layer 3, which represents the base of the C-Zone, is a uniform -30 feet AMSL, an approximate depth of 100 feet bgs. The top elevation of this layer, which represents the base of the B-Zone, is 0 feet AMSL.

The bottom elevations of the model layers are based on geologic logs prepared for soil borings and wells installed at the Hookston Station parcel and nearby areas (ERM 2004) and are typical for this area. Uniform bottom elevations for the three model layers were used as a simplifying assumption in the design of the ground water flow model (Section 2.2.1).

2.2.4   *Flow Conditions*

Flow conditions in Layer 1 (A-Zone) are simulated as unconfined (MODFLOW layer type LAYCON=1) in the Hookston Station ground water flow model. The transmissivity of this layer varies during the model simulation period, and is calculated from the saturated thickness and hydraulic conductivity specified for the layer (McDonald and Harbaugh 1988). Flow conditions in Layer 2 (B-Zone) and Layer 3 (C-Zone) are simulated as unconfined/confined (MODFLOW layer type LAYCON=3). The transmissivities of these model layers vary during the model simulation period, and are calculated from the saturated thickness and hydraulic conductivity specified for the layers (McDonald and Harbaugh 1988). The storage coefficients specified for these model layers may alternate between confined and unconfined values during the model simulation period. This allows the model to realistically simulate the localized dewatering of a confined zone during ground water extraction.

2.2.5   *Flow Boundary Conditions*

The following boundary conditions are used in the Hookston Station ground water flow model:

- The upper boundary of the model grid is a free-surface boundary. The free-surface boundary simulates the water table in the A-Zone. The elevation of this boundary is calculated by MODFLOW during the course of the simulation (McDonald and Harbaugh 1988).

- The lower boundary of the model grid is a no-flow boundary. Downward ground water flow between the C-Zone and the underlying sediments is assumed to be negligible as a simplifying assumption of the model design (Section 2.2.1).

- The southwestern and northeastern margins of the model grid are constant-head boundaries (Figure I-1). These constant-head boundaries simulate the horizontal gradients observed in the ground water flow systems in the Hookston Station area.

- The northwestern and southeastern margins of model grid are no-flow boundaries (Figure I-1). These boundaries of the model grid are approximately parallel to the direction of ground water flow in the A-, B-, and C-Zones.

2.2.6   Aquifer Flow Properties

The values of horizontal hydraulic conductivity that are used in the Hookston Station ground water flow model are:

- A-Zone – horizontal conductivity (Kh) 5.0 feet/day, vertical conductivity (Kv) 0.5 feet/day;

- B-Zone – horizontal conductivity (Kh) 50 feet/day, vertical conductivity (Kv) 5 feet/day; and

- C-Zone – horizontal conductivity (Kh) 50 feet/day, vertical conductivity (Kv) 5 feet/day.

The values of horizontal hydraulic conductivity are representative of the A- and B-Zones based on pumping and slug tests (as described in Appendix G of this FS and Treadwell & Rollo 1993) and are within the range of published values for these types of materials (Fetter 1994). Horizontal hydraulic conductivities are assumed to be 10 times vertical conductivities (Kh/Kv=10:1) in the model layers, which are typical conductivity ratios for moderately stratified aquifers with interbedded silts and clays (Freeze and Cherry 1979; Walton 1988).

2.3   SOLUTE TRANSPORT MODEL

2.3.1   Assumptions of Model Design

The following simplifying assumptions were made in the design of the Hookston Station solute transport model:

- The A-, B-, and C- Zones have uniform values of porosity;

- The A-, B-, and C- Zones have uniform values of longitudinal, transverse, and vertical dispersivity;

- Transverse dispersivities are equal one third of longitudinal dispersivities;

- Vertical dispersivities are equal to one tenth of longitudinal dispersivities;

- The A-, B-, and C-Zones have uniform retardation factors of 1.0 (no sorption by soil matrix); and

- The sources for the VOC plumes in A- and B-Zones are continuous sources with constant concentrations that do not vary over time.

Sorption by the aquifers is not included within the model, as this parameter is largely dependent on the organic content of the aquifer materials. Samples collected from aquifer sands from borings advanced on the Hookston Station parcel (TW-1 through TW-4) contained no detectable amounts of organic carbon (see Table F-1 in Appendix F).

For Alternatives 3 through 6, the solute transport model was run twice. The first run assumed that only the active remedy (e.g., installation of a permeable reactive barrier [PRB]) and dispersion would cause chemical decreases, and that there would be no biodegradation of the plume, which is a conservative modeling assumption. The second run assumes that biodegradation will occur, using a trichloroethylene (TCE) half-life of 19 years for the A-Zone and 4 years for the B-Zone based on bulk attenuation rates calculated from site-specific data (see Appendix D). The one exception to this approach is modeling Alternative 3 (enhanced bioremediation) in the A-Zone, which naturally does assume biodegradation is occurring throughout the plume.

2.3.2   *Transport Boundary Conditions and Initial Transport Conditions*

Constant-concentration boundaries in Layer 1 (A-Zone) and Layer 2 (B-Zone) were used in the Hookston Station solute transport model to simulate three inferred source areas for the VOC plumes in the A- and B-Zones. These constant-concentration boundaries were located near monitoring wells MW-20A/B, MW-13A/B, MW-14A/B. These source terms were added to the model to simulate the consistently high concentrations of dissolved VOCs in ground water near these locations. The concentration value for the constant boundary in Layer 1 (A-Zone)

near monitoring well MW-20A was set at 500 micrograms per liter (µg/L). The concentration values for the other constant-concentration boundaries in Layer 1 (A-Zone) and Layer 2 (B-Zone) were set at 1,000 µg/L.

The initial concentrations for Layer 1 (A-Zone) and Layer 2 (B-Zone) in the transport simulations of the remedial alternatives were the TCE concentrations in the A- and B-Zones during the first quarter of 2006, as depicted in Figures I-2 and I-3.

2.3.3   *Aquifer Transport Properties*

A uniform porosity of 0.25 and a uniform longitudinal dispersivity of 15.9 feet are used for the A-Zone, and a uniform porosity of 0.20 and a uniform longitudinal dispersivity of 16.5 feet are used for the B-Zone in the Hookston Station solute transport model (Appendix D; Walton 1988; Domenico and Schwartz 1990). Transverse dispersivities were assumed to one third of the longitudinal dispersivity (ASTM 1995; USEPA 1986) and vertical dispersivities were assumed to be one tenth of longitudinal dispersivity (USEPA 1986).

3.0   *EVALUATION OF REMEDIAL ALTERNATIVES*

The ground water flow and solute transport models developed for the
Hookston Station were used to evaluate the relative effectiveness of the
following four remedial alternatives presented in the FS:

- Alternative 3 – Bioremediation of the A-Zone and in situ chemical
  oxidation (ISCO) in the B-Zone;

- Alternative 4 – PRB in the A-Zone and ISCO in the B-Zone;

- Alternative 5 – PRB in the A- and B-Zones; and

- Alternative 6 – Pump-and-treat in the A- and B-Zones.

The ground water flow model was also used to determine the number,
location, and flow rates for the withdrawal wells in Alternative 6.

3.1   *ALTERNATIVE 3*

3.1.1   *Simulation of Remedial Systems Operation*

For Alternative 3, bioremediation would be performed in the A-Zone and
ISCO would be used for ground water treatment in the B-Zone. Since
these treatment systems would not significantly impact long-term natural
ground water flow conditions at the Hookston Station parcel and
downgradient study area, the steady-state flow solution from the ground
water model was used to simulate operation of these remedial systems.

3.1.2   *Reduction in TCE Concentrations by Remedial System*

The reduction in TCE concentrations in the A-Zone by bioremediation and
in the B-Zone by ISCO treatment were evaluated with the Hookston
Station solute transport model (Section 2.3). For the bioremediation
simulation, biodegradation was simulated as irreversible, first-order
decay of TCE within the area of Layer 1 (A-Zone) in which injections are
proposed (see Figures 6-5 and 6-6 of the FS). Based on the bulk
attenuation rates calculated for TCE in Appendix D, a biodegradation rate
half-life of 19 years was applied throughout the A–Zone in this
simulation. Bioremediation accelerates natural biodegradation rates by 2

to 8 times (Parsons Corporation 2004). Based on these site-specific degradation rates, a biodegradation rate half-life for the area impacted by the treatment (i.e., the areas immediately surrounding the proposed injection areas) was conservatively estimated to be 2 times the average degradation rate half-life for TCE, or 9.5 years. This accelerated biodegradation rate was also applied to the constant-concentration boundaries representing the inferred source areas (not including the Vincent Road tetrachloroethylene (PCE)/TCE source area), as described in Section 2.3.2.

For the B-Zone ISCO simulation, TCE concentrations were assumed to be instantaneously reduced 90 percent by treatment. Therefore, operation of the ISCO system in the B-Zone was simulated by reducing the initial concentrations in Layer 2 (B-Zone) by 90 percent within the area in which ISCO injections are proposed (see Figures 6-5 and 6-8 of the FS). This is a common simplifying assumption used in modeling short-term in situ chemical mass reductions such as those achieved using ISCO.

The transport simulations were performed with the model code MT3DMS using the steady-state flow solution from the ground water model. The transport simulations were run for a total time of 30 years to evaluate the long-term reduction in TCE concentrations by these remedial systems.

The results of the transport simulation of bioremediation in the A-Zone are shown in Figure I-4. This figure shows the steady-state model head solution (ground water elevation contours) and the TCE concentration solution in the A-Zone 30 years after completion of bioremediation treatment. Time-concentration solutions for three monitoring wells (MW-15A, MW-16A, and MW-17A) downgradient of the treatment areas are shown in Figure I-5. Note that under this simulation, bioremediation treatment is not included for the Vincent Road PCE/TCE plume.

The results of the transport simulation of ground water treatment by ISCO in the B-Zone are shown in Figure I-6. This figure shows the steady-state model head solution and the TCE concentration solution in the B-Zone 30 years after completion of treatment by ISCO. Time-concentration solutions for three downgradient monitoring wells (MW-15B, MW-16B, and MW-17B) are shown in Figure I-7. An additional model run that assumed that in addition to the source reduction due to ISCO treatment in the B-Zone, the remainder of the TCE plume would biodegrade, is presented in Figures I-8 and I-9. These figures show a generally smaller ground water plume at the 30-year time step, and overall faster remediation timeframes due the biodegradation.

It should be noted that this simulation does not include ISCO treatment for the B-Zone Vincent Road PCE/TCE plume, nor enhanced bioremediation for the A-Zone Vincent Road PCE/TCE plume. It should also be noted that in this simulation (and others to be discussed below) the configuration of the plume at the 30-year time step might appear slightly different than the shape of the current plume (e.g., the plume axis appears to be slightly more eastern than the current configuration). This is primarily due to one the simplifying assumptions used in these simulations: a uniform ground water flow field that is aligned with the average ground water flow across the study area (as depicted in Figure I-1). In reality, ground water flow is slightly more dynamic and flow paths are not always in a straight line. However, although these simulations may not precisely match the natural system, the alternatives that were evaluated all use the same simplifying assumptions (such as a uniform flow field), thereby allowing a meaningful comparison between technologies.

3.2   ALTERNATIVE 4

3.2.1   Simulation of Remedial Systems Operation

In Alternative 4, a PRB would be installed in the A-Zone and ISCO would be used for ground water remediation in the B-Zone. Since these treatment systems would not significantly impact long-term natural ground water flow conditions at the parcel and downgradient study area, the steady-state flow solution from the ground water flow model was used to simulate long-term operation of these remedial systems.

3.2.2   Reduction in TCE Concentrations by Remedial System

The reduction in TCE concentrations in the A-Zone by long-term operation of the PRB and in the B-Zone by ISCO treatment were evaluated with the Hookston Station solute transport model (Section 2.3). For the PRB simulation, only the A-Zone TCE plume downgradient of the PRB was simulated with the model, since the PRB would treat the upgradient TCE, and the area of interest for the modeling is the downgradient effect of the PRB.

The ISCO treatment in the B-Zone is identical to that described in Alternative 3 (Section 3.1).

The A-Zone transport simulation was performed with the model code MT3DMS using the steady-state flow solution from the ground water model. The transport simulation was run for a total time of 30 years to evaluate the long-term reduction in TCE concentrations by the PRB.

The results of the transport simulation of the long-term operation of the PRB in the A-Zone are shown in Figure I-10. This figure shows the location of the PRB, the steady-state model head solution, and the TCE concentration solution in the A-Zone after 30 years of operation of the remedial system (downgradient of the PRB). Time-concentration solutions for three downgradient monitoring wells (MW-15A, MW-16A, and MW-17A) and a modeled observation well (an imaginary well placed roughly midway between MW-15A and MW-16A (see Figure I-10) are shown in Figure I-11. This simulation assumes no biodegradation of the plume.

Figure I-12 depicts the TCE concentration solution in the A-Zone after 30 years of operation, assuming a TCE half-life of 19 years. Figure I-13 provides time-concentration estimates for the four above-listed monitoring wells, assuming that biodegradation is acting on the remaining plume downgradient of the PRB.

The result of the transport simulation of ground water treatment by ISCO in the B-Zone is described above under Alternative 3 (Figure I-3).

3.3   ALTERNATIVE 5

3.3.1   *Simulation of Remedial System Operation*

In Alternative 5, a PRB would be installed in the A- and B-Zones. Since the PRB would not impact natural ground water flow conditions at the Hookston Station parcel and downgradient study area, the steady-state flow solution from the ground water model was used to simulate long-term operation of this remedial system.

3.3.2   *Reduction in TCE Concentrations by Remedial System*

The reduction in TCE concentrations in the A- and B-Zones by long-term operation of the PRB was evaluated with the Hookston Station solute transport model (Section 2.3). Similar to Alternative 4, for these simulations, only the TCE plume downgradient of the PRB was simulated

with the model, since the PRB would treat upgradient TCE, and the area of interest for the modeling is the downgradient effect of the PRB.

The transport simulations were performed with the model code MT3DMS using the steady-state flow solution from the ground water model. The transport simulations were run for a total time of 30 years to evaluate the reduction in TCE concentrations by long-term operation of this remedial system.

The results of the transport simulation for the A-Zone are discussed above under Alternative 4 (Section 3.2). The results of the transport simulation for the B-Zone PRB are shown in Figure I-14. This figure shows the location of the PRB, the steady-state model head solution, and the TCE concentration solution in the B-Zone after 30 years of operation of the remedial system. Time-concentration solutions for three downgradient monitoring wells (MW-15B, MW-16B, and MW-17B) are shown in Figure I-15. This simulation assumes no biodegradation of the plume.

Figure I-16 depicts the TCE concentration solution in the B-Zone after 30 years of operation, assuming a TCE half life of 4 years. Figure I-17 provides time-concentration estimates for the above-listed monitoring wells, assuming that biodegradation is acting on the remaining plume downgradient of the PRB.

3.4   ALTERNATIVE 6

3.4.1   Simulation of Remedial System Operation

In Alternative 6, ground water extraction wells would be installed in the A- and B-Zones to capture and treat the VOC plume. Operation of the pump-and-treat system was simulated by adding well nodes (point sinks) to Layer 1 (A-Zone) and Layer 2 (B-Zone) of the ground water flow model to represent the extraction wells. The pumping rate of the well nodes in Layer 1 (A-Zone) was set at 2 gallons per minute and the pumping rate of the wells nodes in Layer 2 (B-Zone) was set at 50 gallons per minutes (Section 2.2.6). The model was then solved for steady-state flow conditions to simulate long-term operation of the pump-and-treat system. The number and location of the well nodes were varied in successive simulations to achieve horizontal and vertical capture of the core of the VOC plume (within the 500 µg/L concentration contour) in the A- and B-Zones.

3.4.2 *Ground Water Capture by Remedial System*

The effectiveness of ground water capture by the extraction wells was evaluated by calculating ground water flow paths to the extraction wells for the head solution from the simulation of treatment system operation (Section 3.4.1) using the particle tracking code PATH3D. Ground water capture by the extraction wells was evaluated by placing particles in Layer 1 (A-Zone) and Layer 2 (B-Zone) along the VOC plume boundaries. For the particle tracking simulations, a uniform effective porosity of 0.25 and retardation factor of 1.0 was used for Layer 1 (A-Zone), and a uniform effective porosity of 0.20 and retardation factory of 1.0 was used for Layer 2 (B-Zone). Path lines were calculated for steady-state flow conditions to fully delineate the ultimate flow paths of the particles within the model grid.

The results of the particle tracking simulations of the withdrawal well systems are shown in Figures I-19 and I-20. These figures show the location of the (hypothetical) extraction wells, the steady-state pumping head solution, and the modeled flow path solution for the withdrawal well systems in the A- and B-Zones. Based on the results of the particle tracking simulation, 15 A-Zone extraction wells to capture the core of the ground water plume (within the 500 μg/L concentration contour). Because of the increased transmissivity of the B-Zone, a fewer number of wells can be used to impart greater hydraulic influence. The model simulations indicate five B-Zone wells could achieve hydraulic capture over a broader area.

3.4.3 *Reduction in TCE Concentrations by Remedial System*

The reduction in TCE concentrations in the A- and B-Zone by long-term operation of the pump-and-treat system was evaluated with the Hookston Station solute transport model (Section 2.3). The transport simulations were performed with the model code MT3DMS using the steady-state ground water flow solution from the simulation of the remedial system operation (Section 3.4.1). The transport simulations were run for a total time of 30 years to evaluate the reduction in TCE concentrations by long-term operation of the remedial system.

The results of the transport simulations of the operation of the pump-and-treat system for the A-Zone are shown in Figure I-20. This figure shows the location of the extraction wells, the steady-state pumping head solution, and the TCE concentration solution in the A-Zone after 30 years of ground water withdrawal. Time-concentration solutions for three

downgradient monitoring wells (MW-15A, MW-16A, and MW-17A) and a modeled observation well (an imaginary well placed roughly midway between MW-15A and MW-16A) are shown in Figure I-21. A modeled TCE concentration map and a time versus concentration graph for the above-listed wells, assuming biodegradation will affect the plume over time, are provided as Figures I-22 and I-23, respectively.

B-Zone simulations of the pump-and-treat alternative are similarly shown in Figures I-24 and I-25 (assuming no biodegradation), and Figures I-26 and I-27 (assuming biodegradation).

4.0   *COMPARISON OF MODELING RESULTS*

Modeling of four of the A-Zone remediation alternatives suggests that the timeframes necessary to achieve reductions in TCE concentration below 530 µg/L (the San Francisco Bay Regional Water Quality Control Board screening level for protection of indoor air vapor intrusion) range from approximately 2 to 5 years. Alternative 3 (in-situ bioremediation) shows concentration decreases to this level in slightly less than 5 years. Alternatives 4 and 5 (PRBs in the A-Zone), estimate a 2 to 3 year timeframe to achieve this level, depending on whether biodegradation of the plume is accounted. Alternative 6 (pump-and-treat) appears to be slightly faster, with 2 to 2.5 year timeframes to reduce concentrations down the axis of the plume to levels below 530 µg/L. Note that the initial TCE concentrations in these downgradient plume axis wells are currently just over 530 µg/L. Based on the assumptions used to create the model, concentration decreases to very low levels (e.g., the Maximum Contaminant Levels) will be achieved over a longer timeframe, which in some portions of the plume may be more than 30 years.

Modeling of the three B-Zone remedial alternatives (ISCO, PRB, and pump-and-treat) suggests that significant reductions will be achieved in the downgradient axis wells within an approximate 2 to 8 year timeframe. The model simulations indicate a potential for short-term increases in the downgradient plume-axis wells, representing high concentrations between MW-14B and MW-15B that pass through the system. Compared with the A-Zone, concentrations generally approach the Maximum Contaminant Levels more quickly in the B-Zone, partly due to the increased ground water flow and (for the modeling runs that assume biodegradation) due to the increased biodegradation rate observed in the B-Zone.

These modeling results have been used in the FS to evaluate the relative effectiveness of the alternatives.

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Figures

Figures

200 COLUMNS

CONSTANT HEAD BOUNDARY

NO FLOW BOUNDARY

NO FLOW BOUNDARY

250 ROWS

CONSTANT HEAD BOUNDARY

HOOKSTON PARCEL
PROPERTY BOUNDARY

N

0

FEET

800

Figure I-1
Model Grid
Hookston Station
Pleasant Hill, California

ERM   07/06

LEGEND

5 ⌇ TCE Concentration Contour (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

0   300
FEET
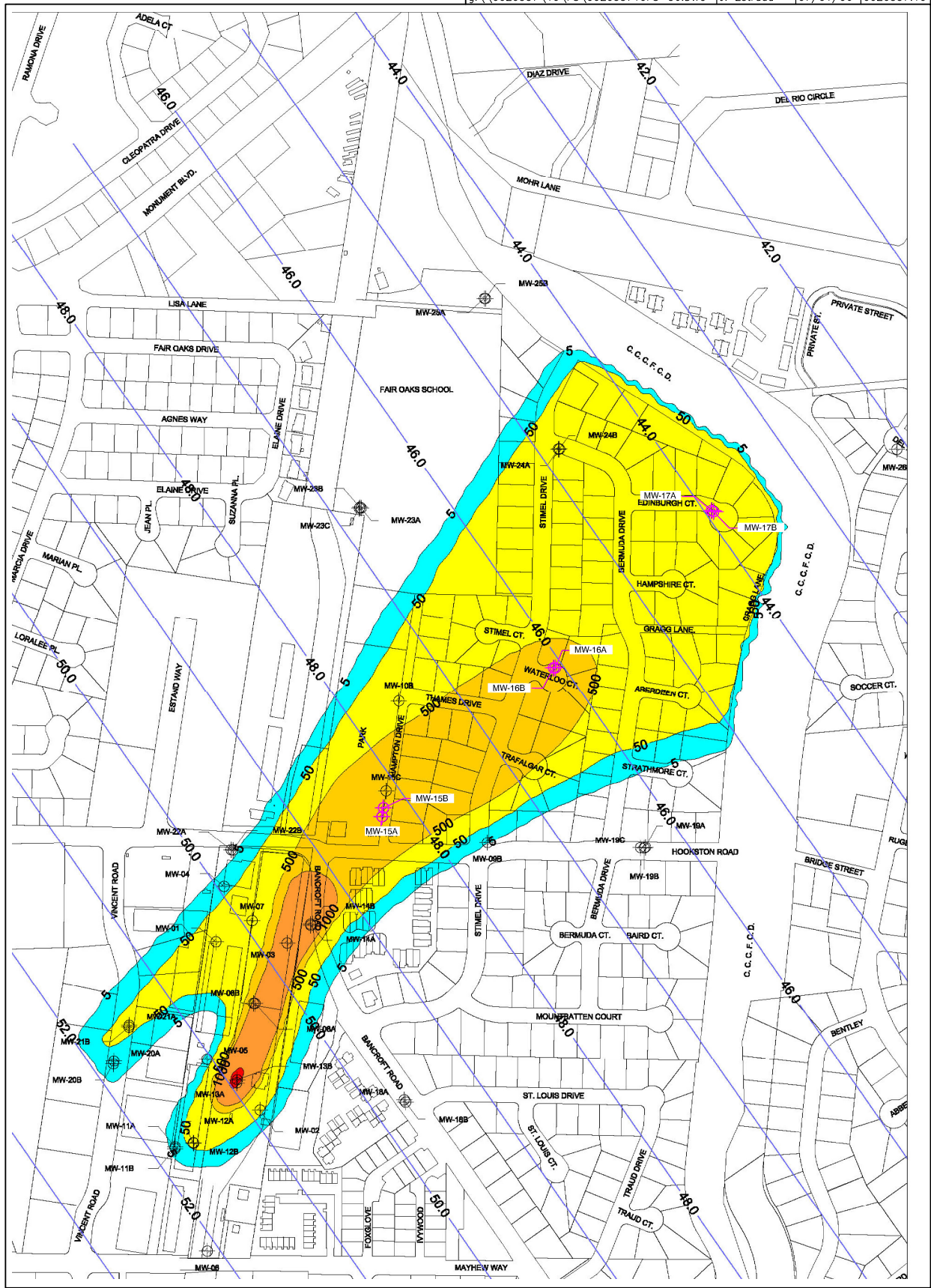
Figure I-2
Initial TCE Concentration in A-Zone
Hookston Station
Pleasant Hill, California
ERM   *07/06*

LEGEND

5 ⌇ TCE Concentration Contour (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

0   300
FEET

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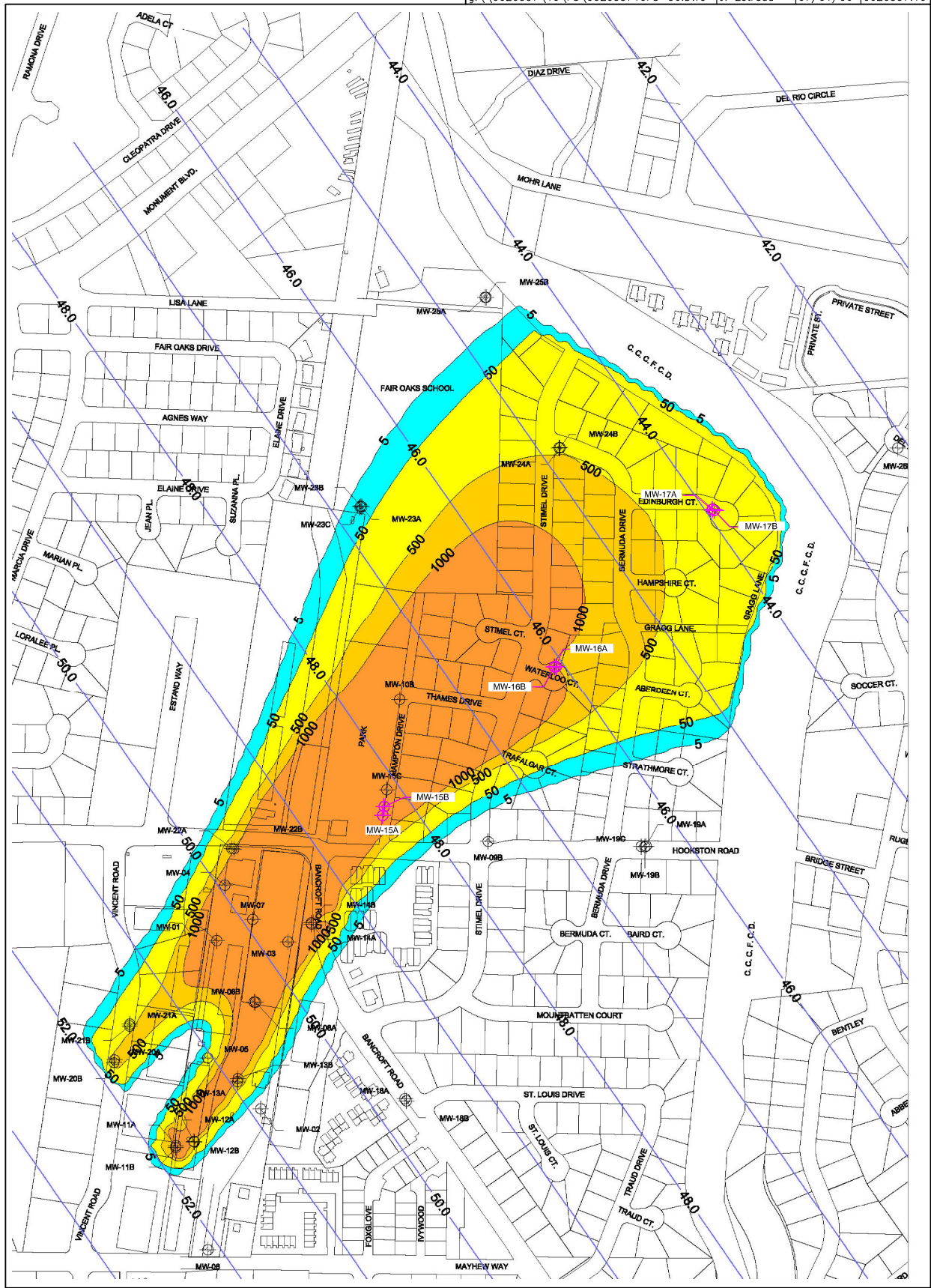
Figure I-3
Initial TCE Concentration in B-Zone
Hookston Station
Pleasant Hill, California

ERM   *07/06*

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

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FEET
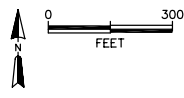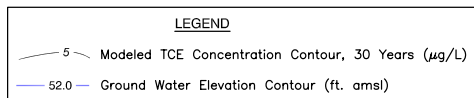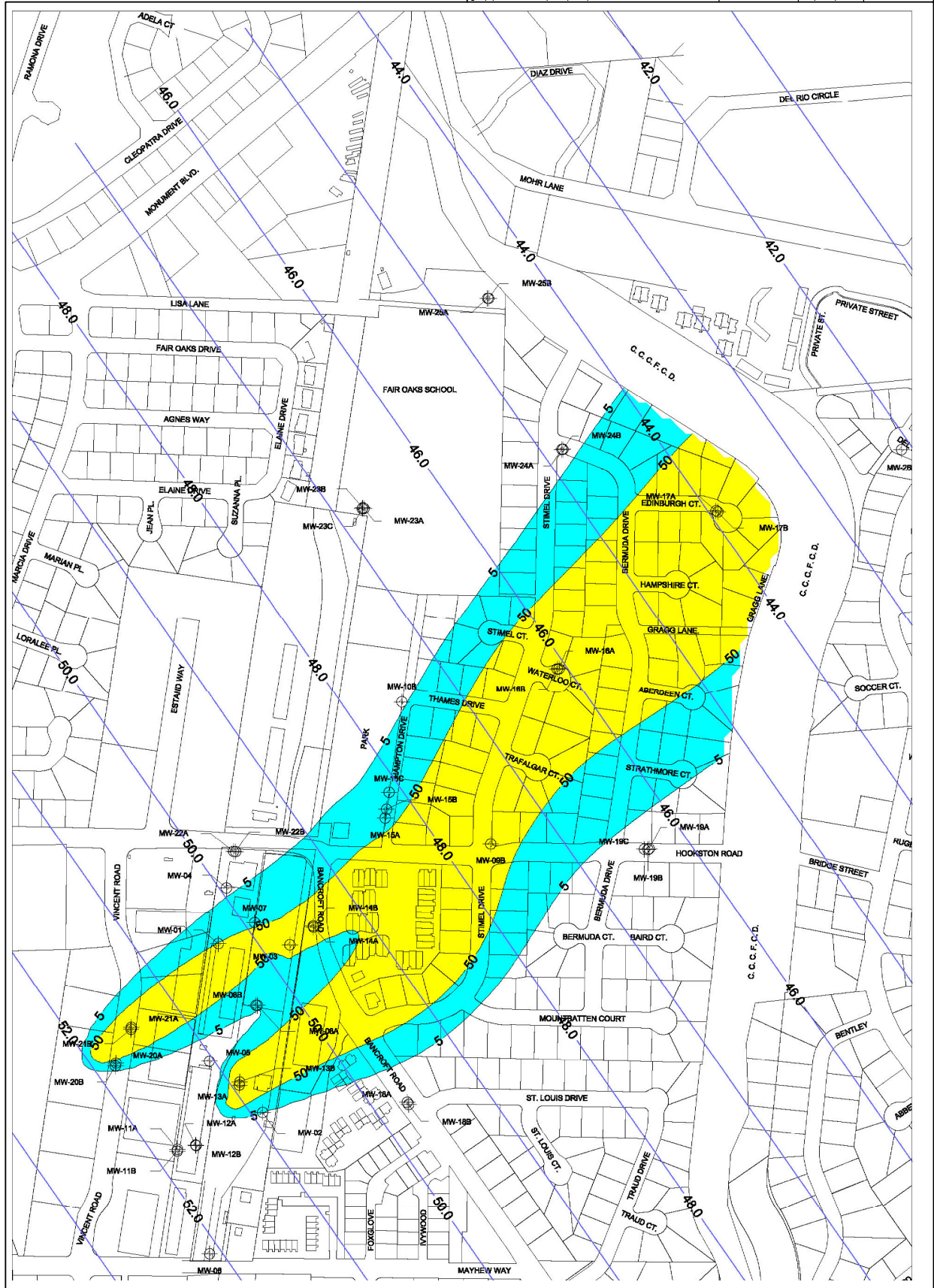
Figure I-4

Alternative 3
Bioremediation in A-Zone, TCE Concentration Solution
Simulation Time 30 Years
Hookston Station
Pleasant Hill, California
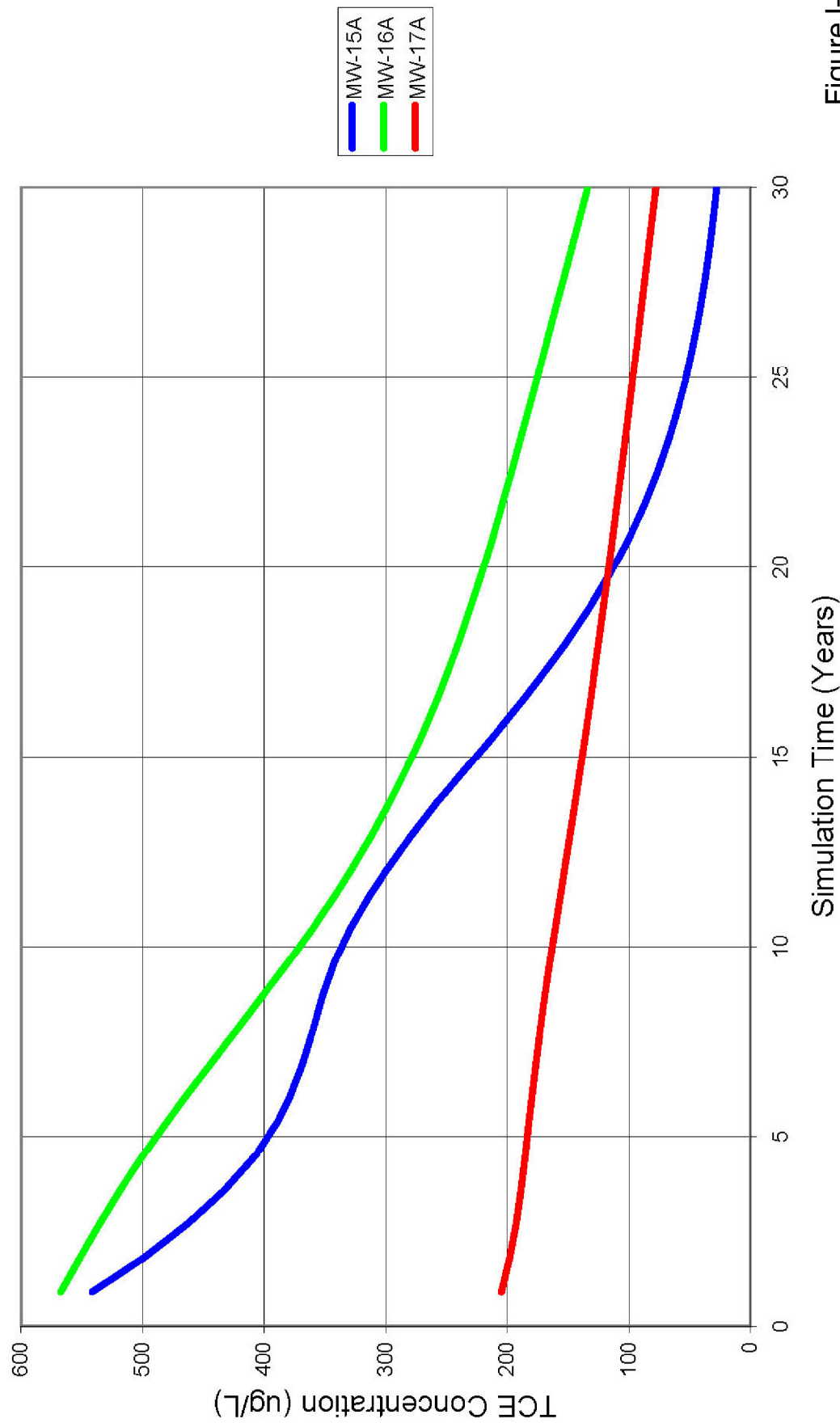
ERM   *07/06*

Figure I-5
Alternative 3
Bioremediation in A-Zone
Modeled Concentration vs. Time at Selected A Zone Wells
Hookston Station
Pleasant Hill, California

ERM   07/06

| CAD File:
g:\\0020557\10\FS\0020055710FS-50.DWG | Drawn By:
J. Estrada | Date:
07/03/06 | Project No.
0020557.10 |

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

0   300
FEET

N

Figure I-6
Alternative 3
Chemical Oxidation in B-Zone, No Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California
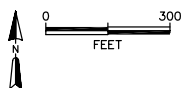
ERM   *07/06*

Figure I-7
Alternative 3
Chemical Oxidation in B-Zone, No Degradation
Modeled Concentration vs. Time at Selected B Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

0   300
FEET
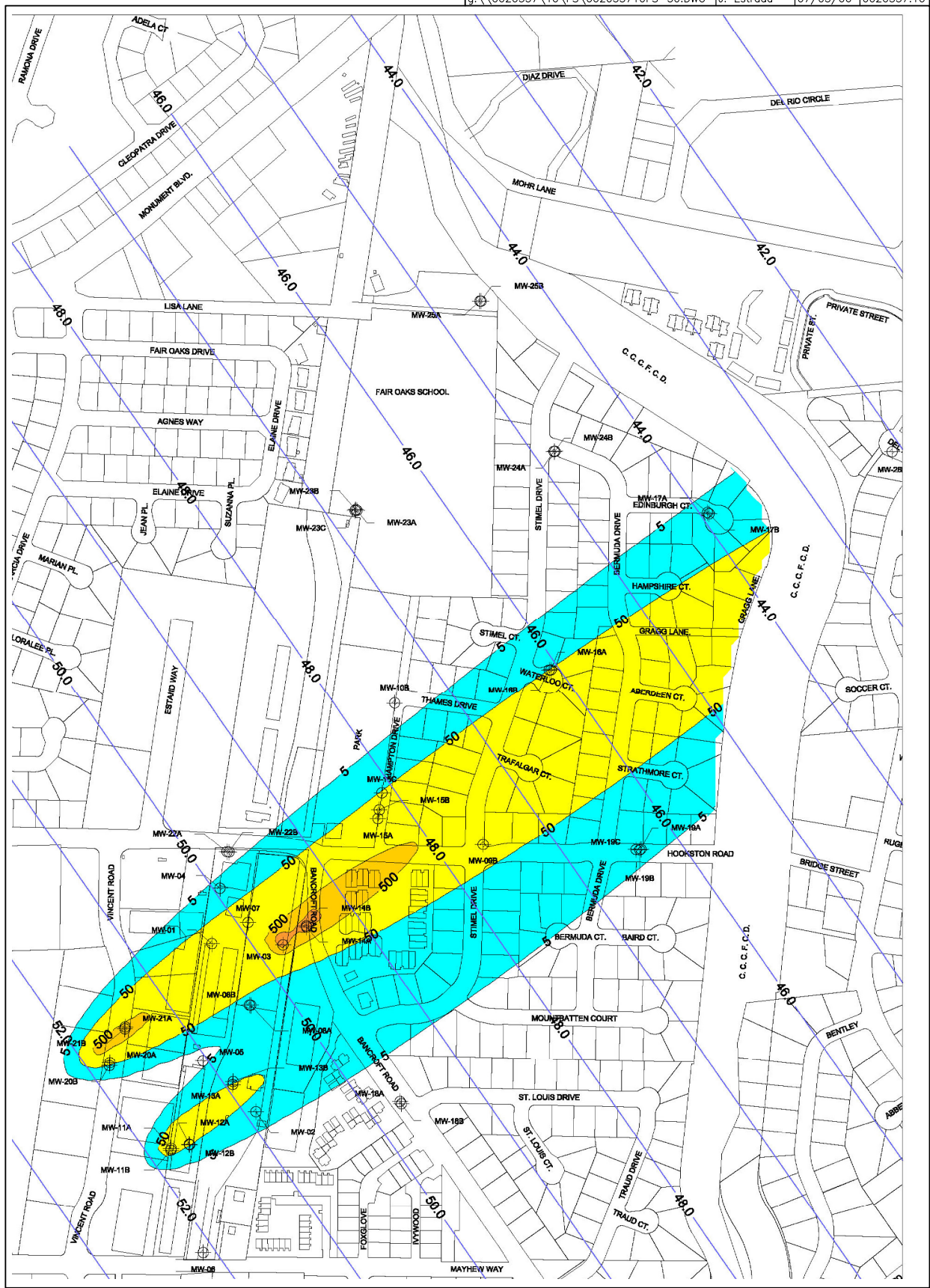
Figure I-8
Alternative 3
Chemical Oxidation in B-Zone, With Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California

ERM   07/06

TCE Concentration (ug/L)

Simulation Time (Years)

Legend:
- MW-15B
- MW-16B
- MW-17B

Chemical Oxidation in B-Zone, With Degradation
Modeled Concentration vs. Time at Selected A Zone Wells
Hookston Station
Pleasant Hill, California

Figure I-9
Alternative 3

PLUME DIMENSIONS
UPGRADIENT OF PRB NOT
MODELED

LEGEND

— 5 — Modeled TCE Concentration Contour, 30 Years (µg/L)

— — 5 — — Current TCE Concentration Contour (µg/L)

—— 52.0 —— Ground Water Elevation Contour (ft. amsl)

0   300
FEET

N

Figure I-10
Alternative 4
PRB in A-Zone, No Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California
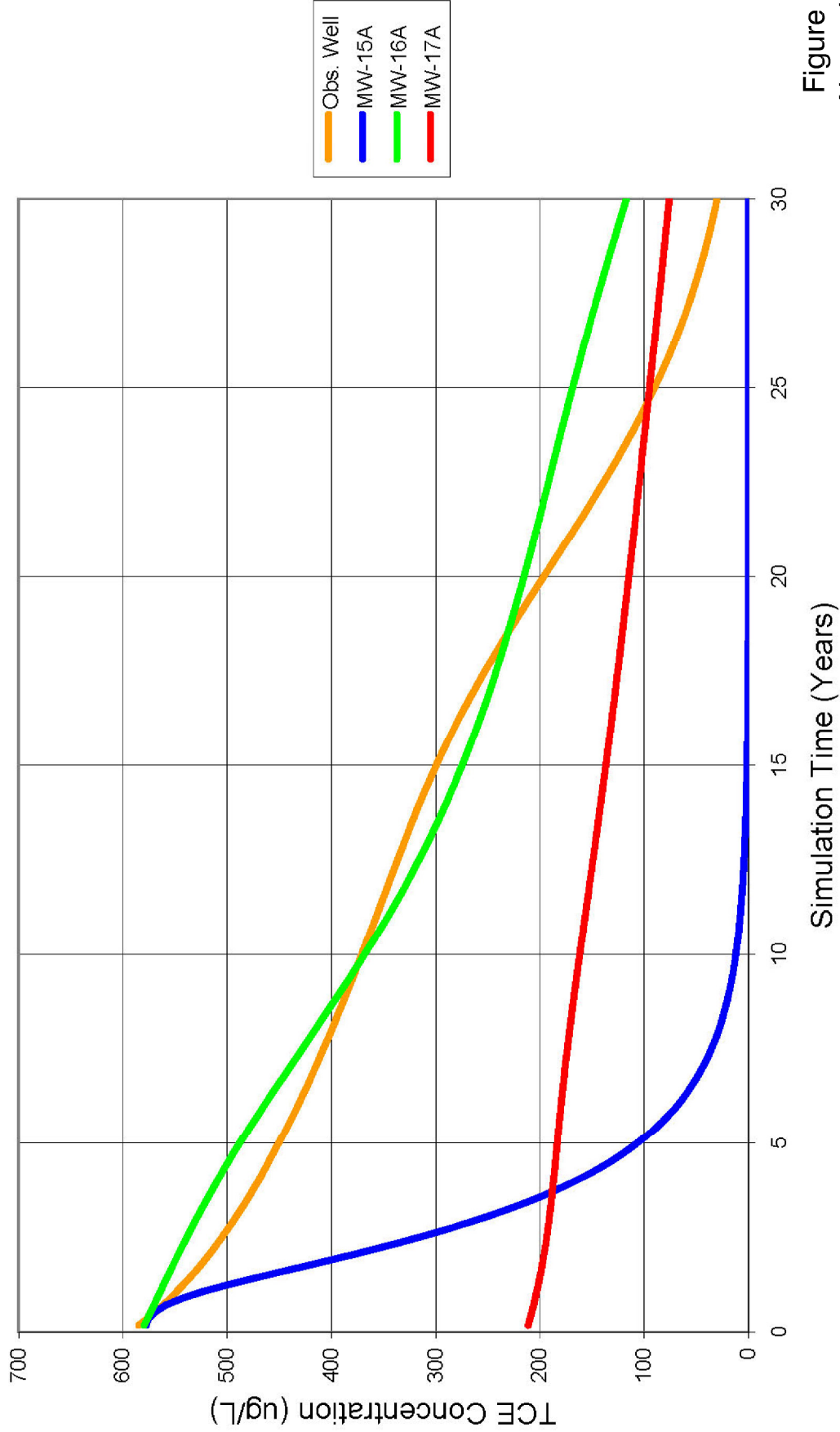
ERM   *07/06*

Figure I-11
Alternative 4
PRB in A-Zone, No Degradation
Modeled Concentration vs. Time at Selected A Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*

PLUME DIMENSIONS UPGRADIENT OF PRB NOT MODELED

LEGEND

—5—⌒ Modeled TCE Concentration Contour, 30 Years (µg/L)

– –5– – Current TCE Concentration Contour (µg/L)

——52.0—— Ground Water Elevation Contour (ft. amsl)

0   300
FEET

N

Figure I-12
Alternative 4
PRB in A-Zone, With Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California

ERM   *07/06*

Figure I-13
Alternative 4
PRB in A-Zone, With Degradation
Modeled Concentration vs. Time at Selected A Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*

Legend:
- Obs. Well
- MW-15A
- MW-16A
- MW-17A

Y-axis: TCE Concentration (ug/L)
X-axis: Simulation Time (Years)

PLUME DIMENSIONS
UPGRADIENT OF PRB NOT
MODELED

LEGEND

— 5 ⌐ Modeled TCE Concentration Contour, 30 Years (µg/L)

— 5 — Current TCE Concentration Contour (µg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

0   300
FEET

N

Figure I-14
Alternative 5
PRB in B-Zone, No Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston StatioN
Pleasant Hill, California

ERM   *07/06*

Figure I-15
Alternative 5
PRB in B-Zone, No Degradation
Modeled Concentration vs. Time at Selected B Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*

Legend:
- MW-15B
- MW-16B
- MW-17B

X-axis: Simulation Time (Years)
Y-axis: TCE Concentration (ug/L)

PLUME DIMENSIONS UPGRADIENT OF PRB NOT MODELED

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

5 — Current TCE Concentration Contour (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)
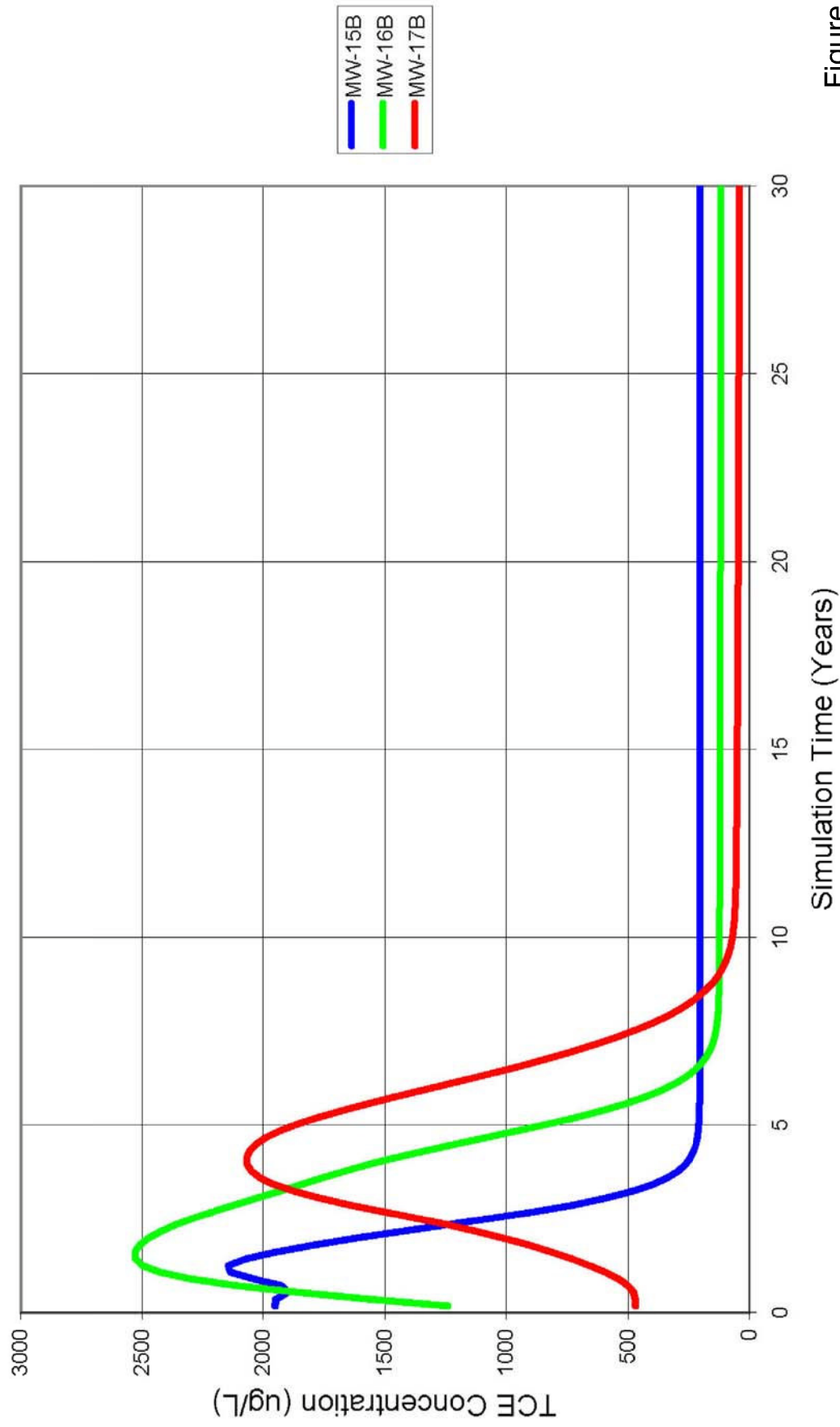
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Figure I-17
Alternative 5
PRB in B-Zone, With Degradation
Modeled Concentration vs. Time at Selected B Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*

Legend:
MW-15B
MW-16B
MW-17B

TCE Concentration (ug/L)

Simulation Time (Years)

LEGEND

TCE Plume
52.0 — Ground Water Elevation Contour (ft. amsl)
Ground Water Capture Flowline Path (Modeled)
Ground Water Extraction Well (Hypothetical)

0   300
FEET
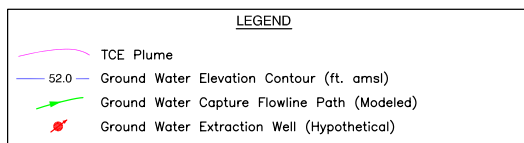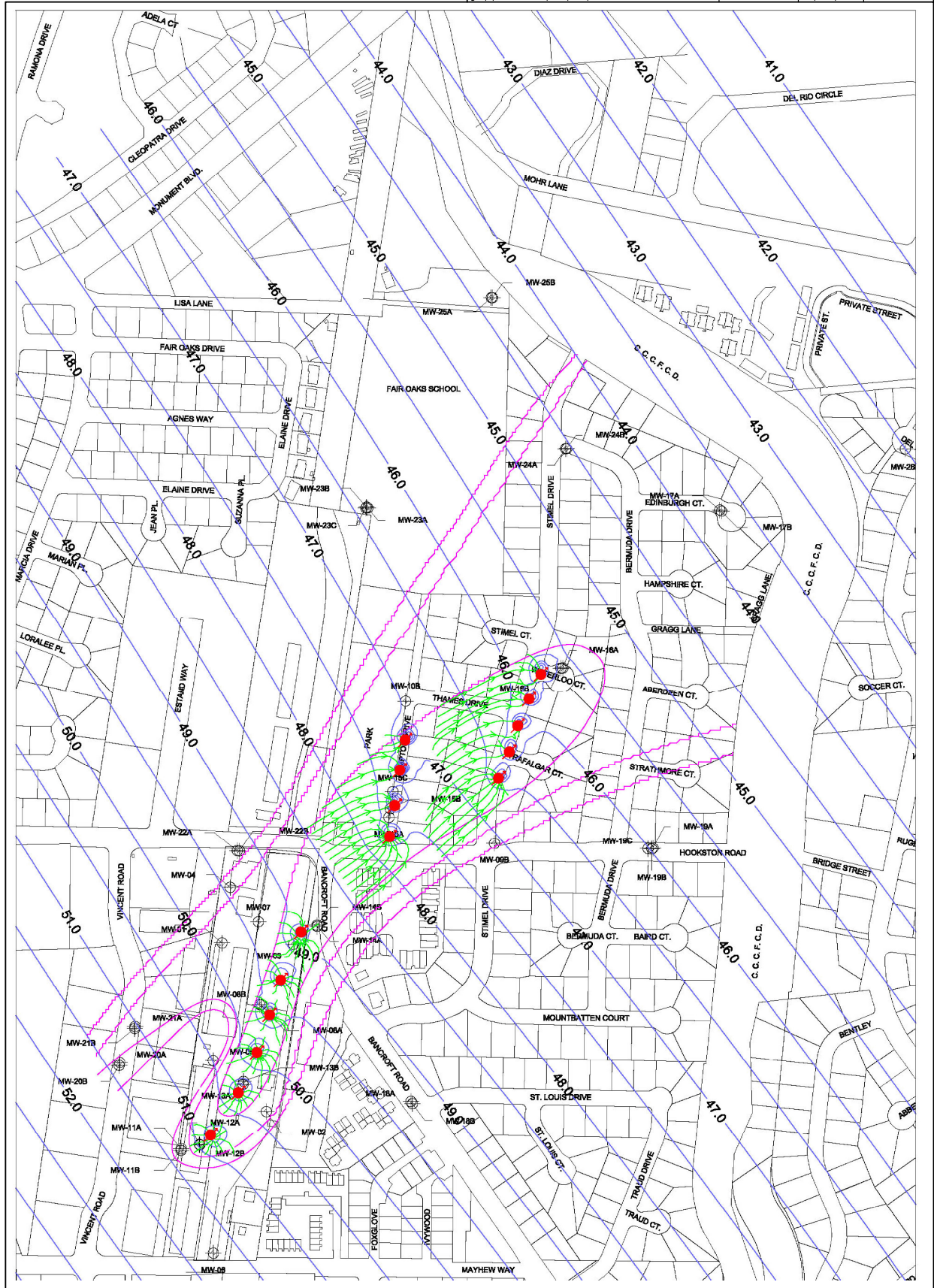
Figure I-18
Alternative 6
Pump and Treat
Ground Water Flow Path Solution, A-Zone
Hookston Station
Pleasant Hill, California

ERM   *07/06*

LEGEND

⎯⎯⎯ TTCE Plume

⎯ 52.0 ⎯ Ground Water Elevation Contour (ft. amsl)

→→→ Ground Water Capture Flowline Path (Modeled)

● Ground Water Extraction Well (Hypothetical)

0   300
FEET
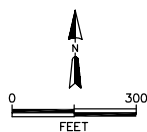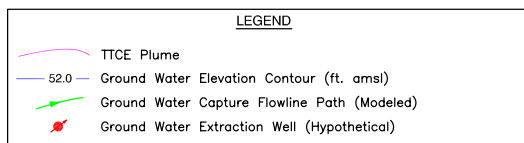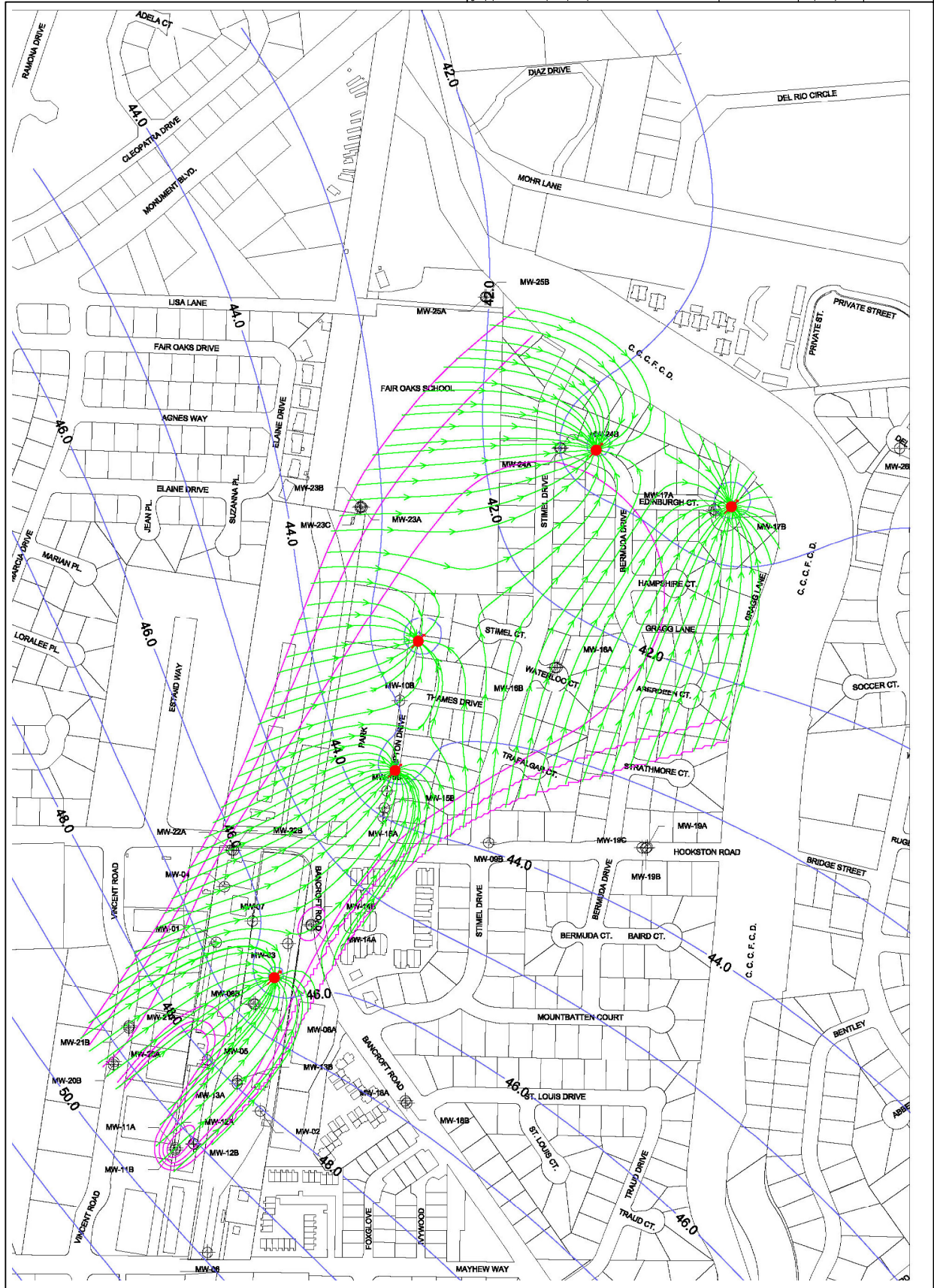
Figure I-19
Alternative 6
Pump and Treat
Ground Water Flow Path Solution, B-Zone
Hookston Station
Pleasant Hill, California

ERM   *07/06/*

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

● Ground Water Extraction Well (Hypothetical)

Figure I-20
Alternative 6
Pump and Treat in A-Zone, No Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California
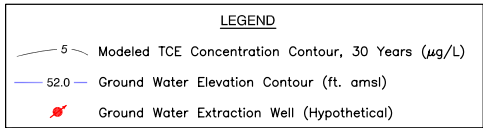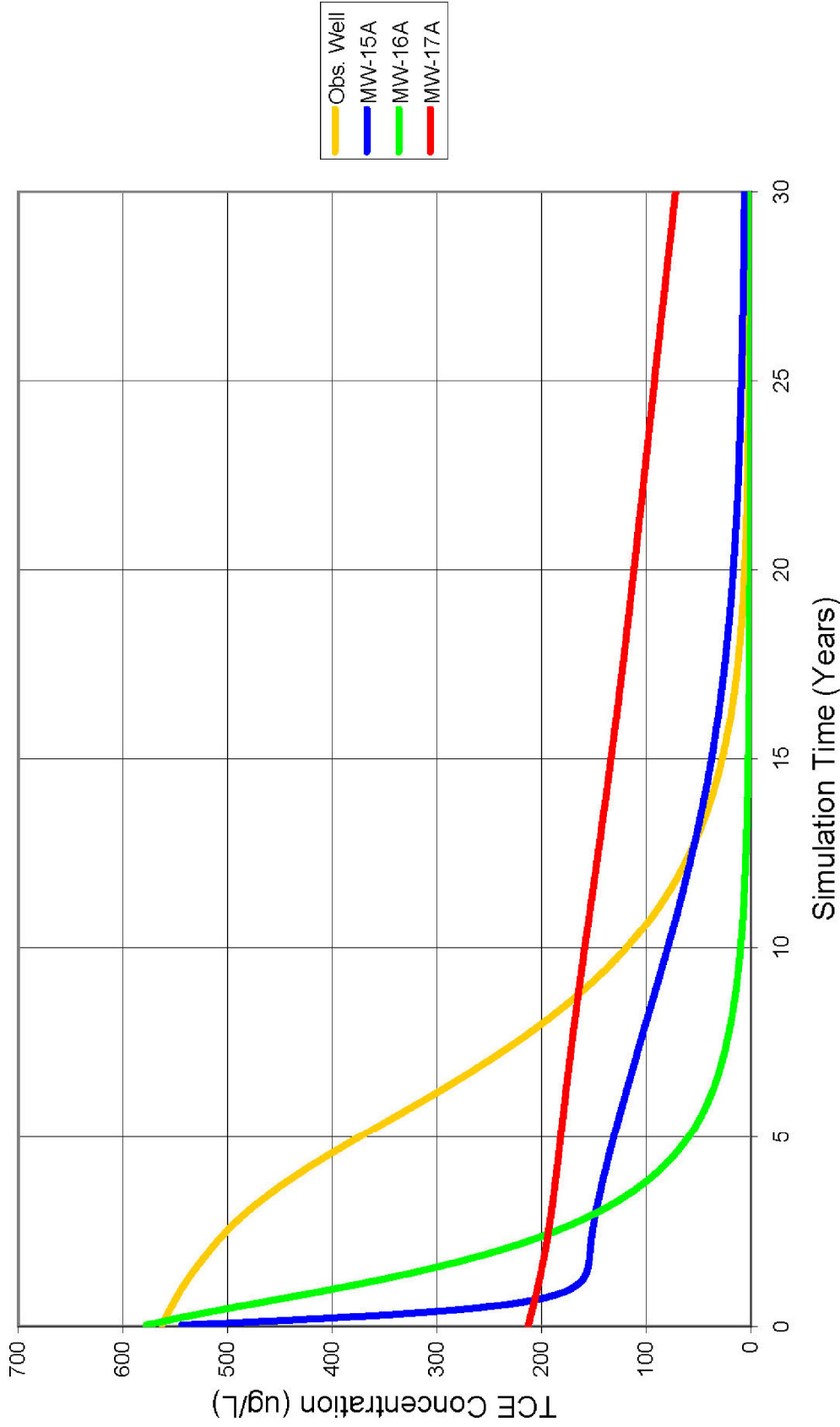
ERM   *07/06*
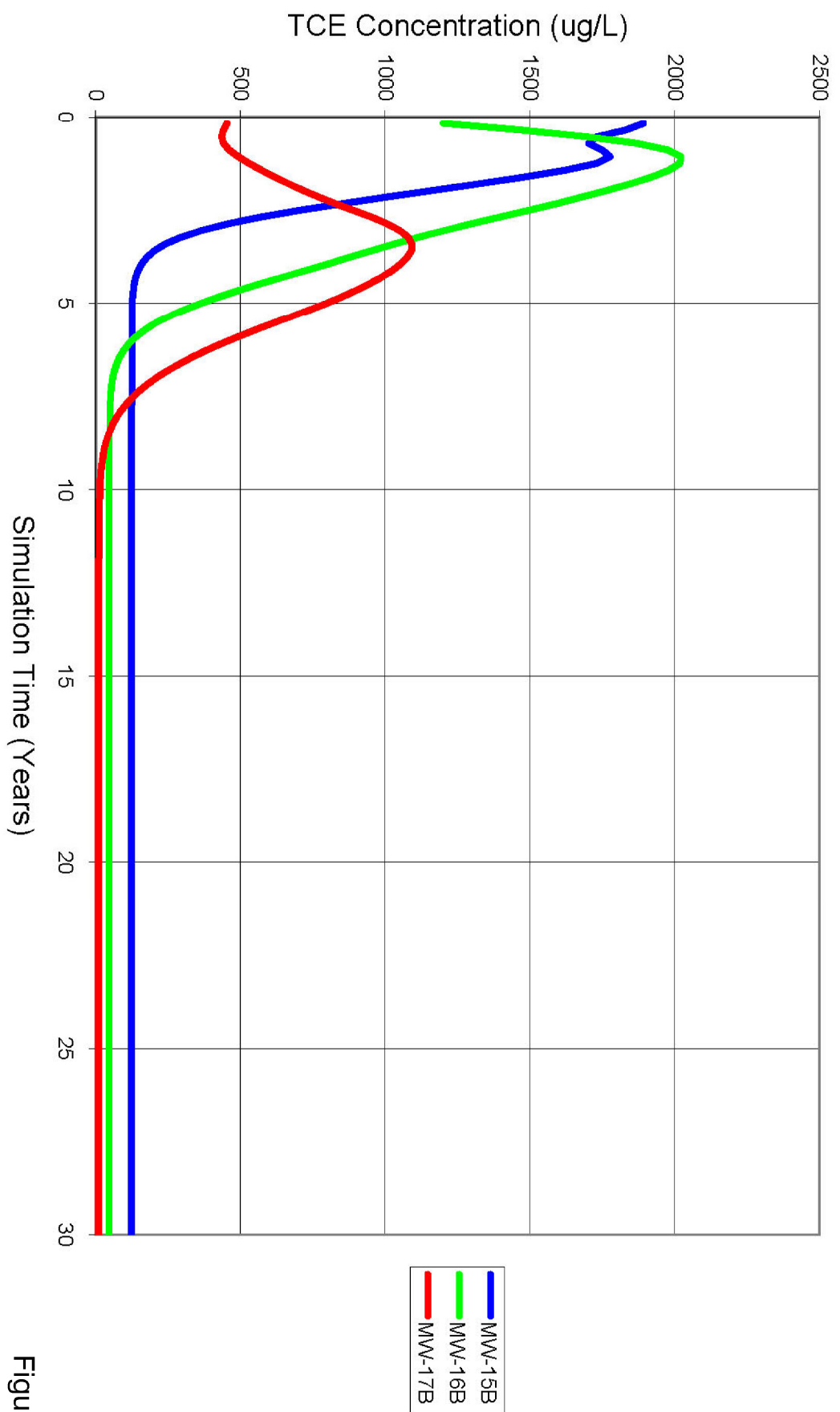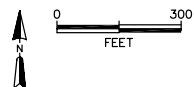
Figure I-21

Alternative 6

Pump and Treat in A-Zone, No Degradation

Modeled Concentration vs. Time at Selected A Zone Wells
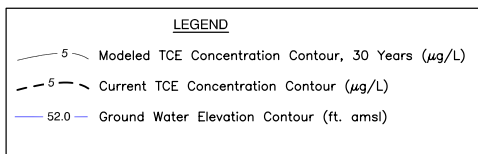
Hookston Station

Pleasant Hill, California

ERM   *07/06*

LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

● Ground Water Extraction Well (Hypothetical)

0   300
FEET
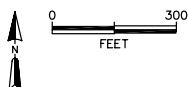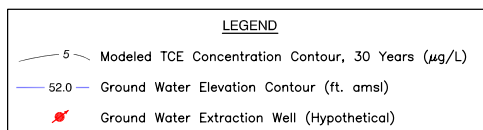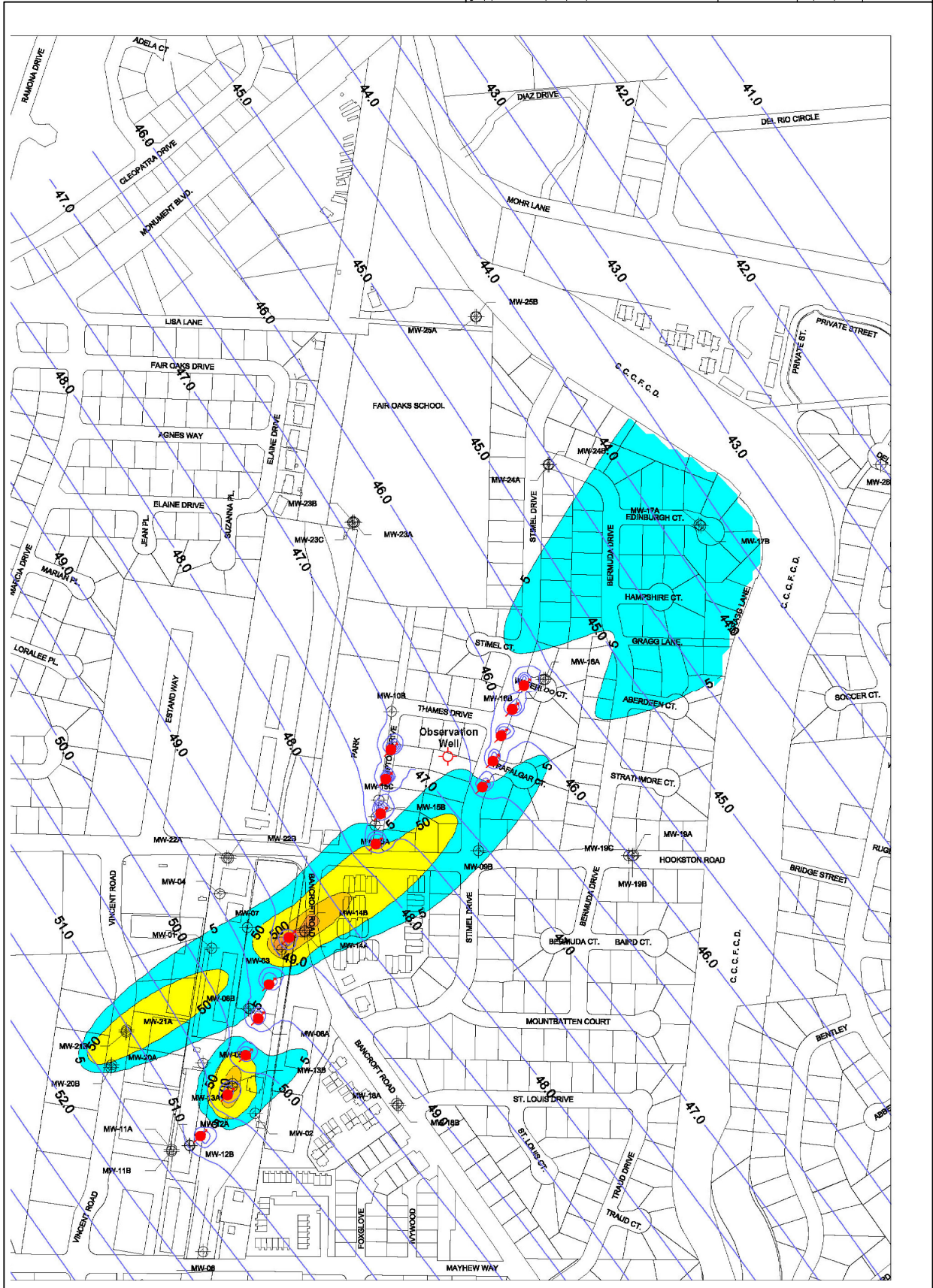
Figure I-22
Alternative 6
Pump and Treat in A-Zone, With Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California

ERM   *07/06*
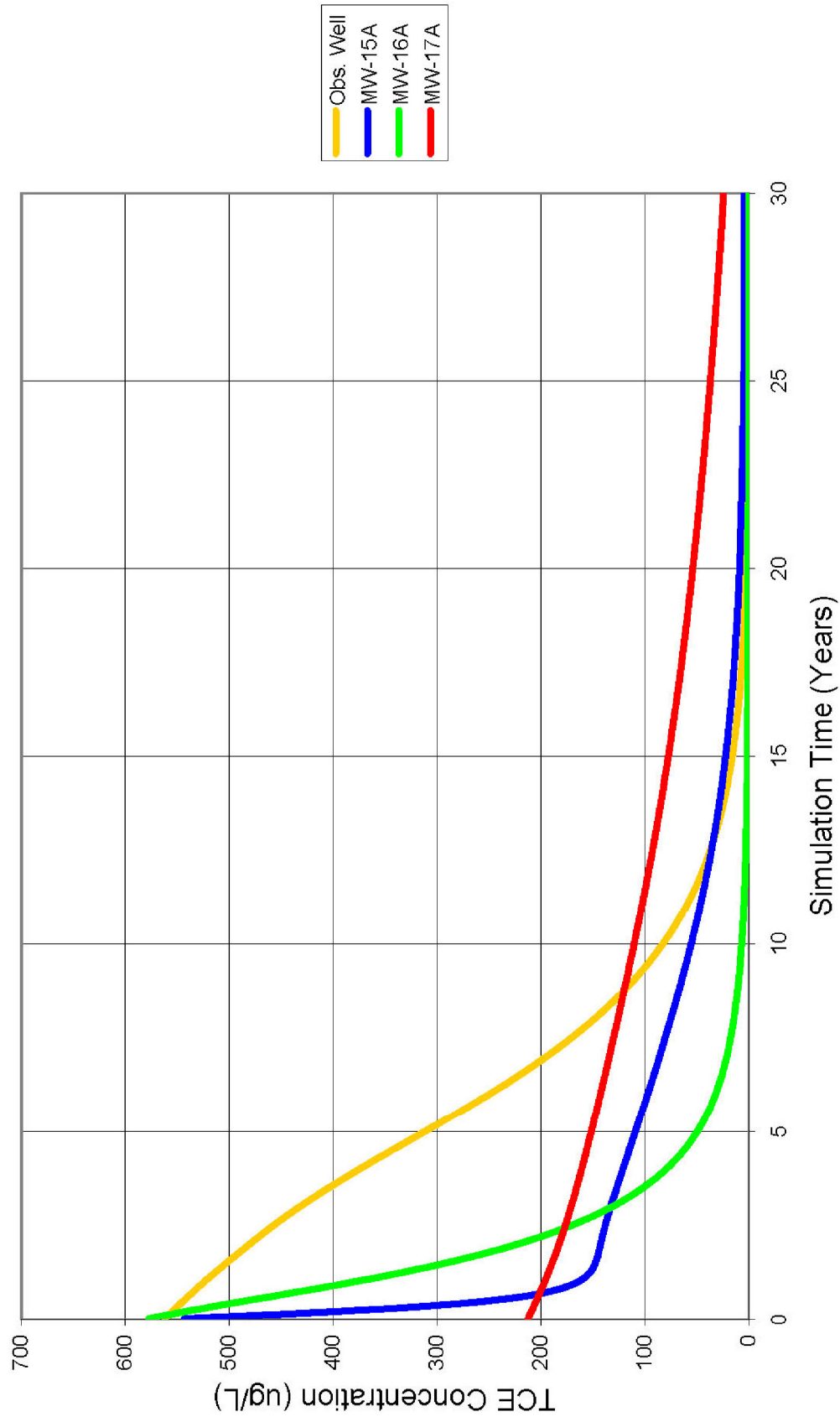
Figure I-23
Alternative 6
Pump and Treat in A-Zone, With Degradation
Modeled Concentration vs. Time at Selected A Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*
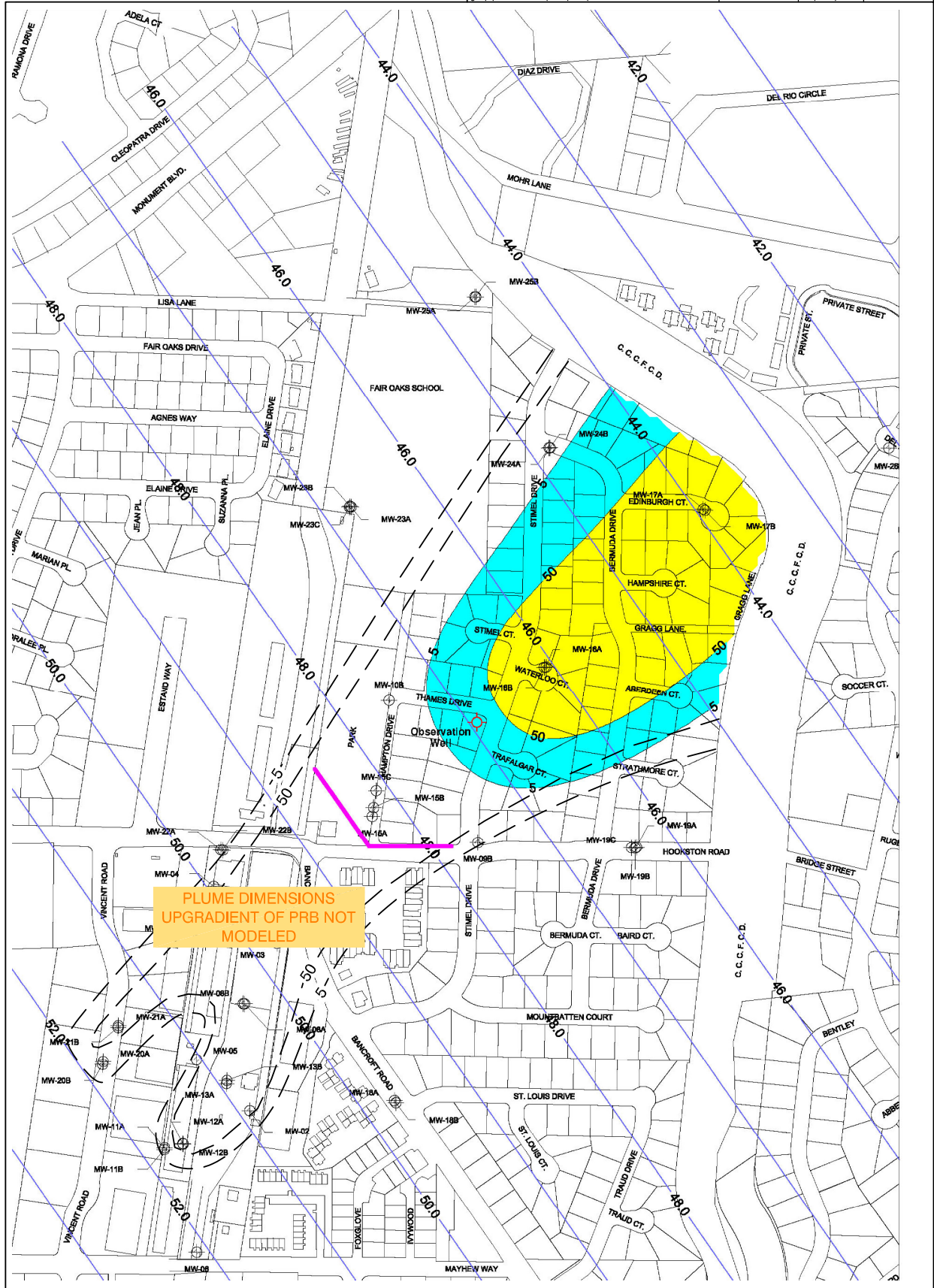
LEGEND

5 — Modeled TCE Concentration Contour, 30 Years (μg/L)

52.0 — Ground Water Elevation Contour (ft. amsl)

● Ground Water Extraction Well (Hypothetical)

0   300
FEET
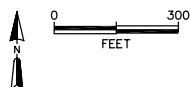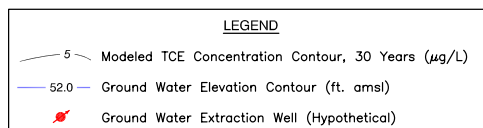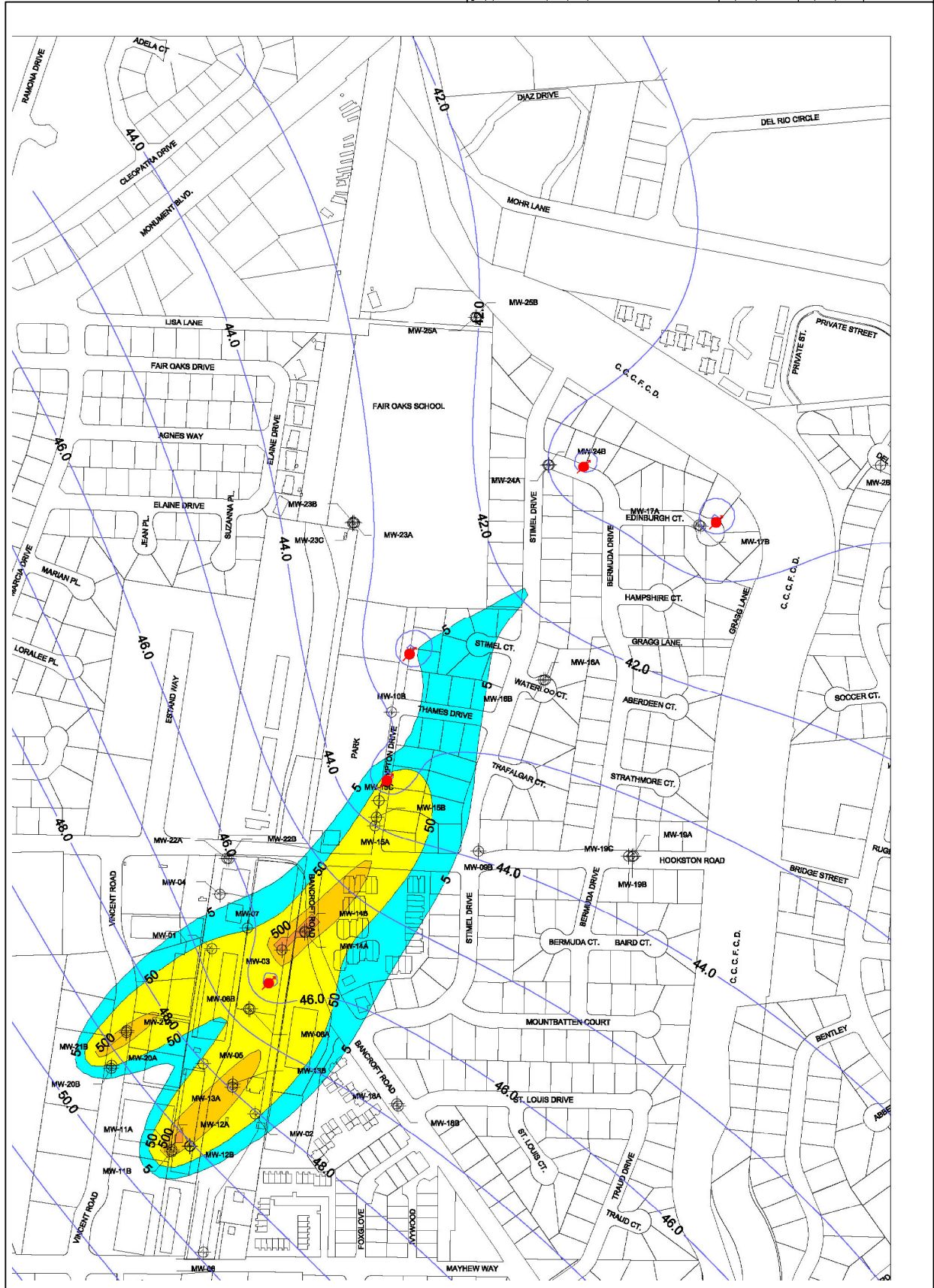
Figure I-24
Alternative 6
Pump and Treat in B-Zone, No Degradation
TCE Concentration Solution, Simulation Time 30 Years
Hookston Station
Pleasant Hill, California

ERM   *07/06*
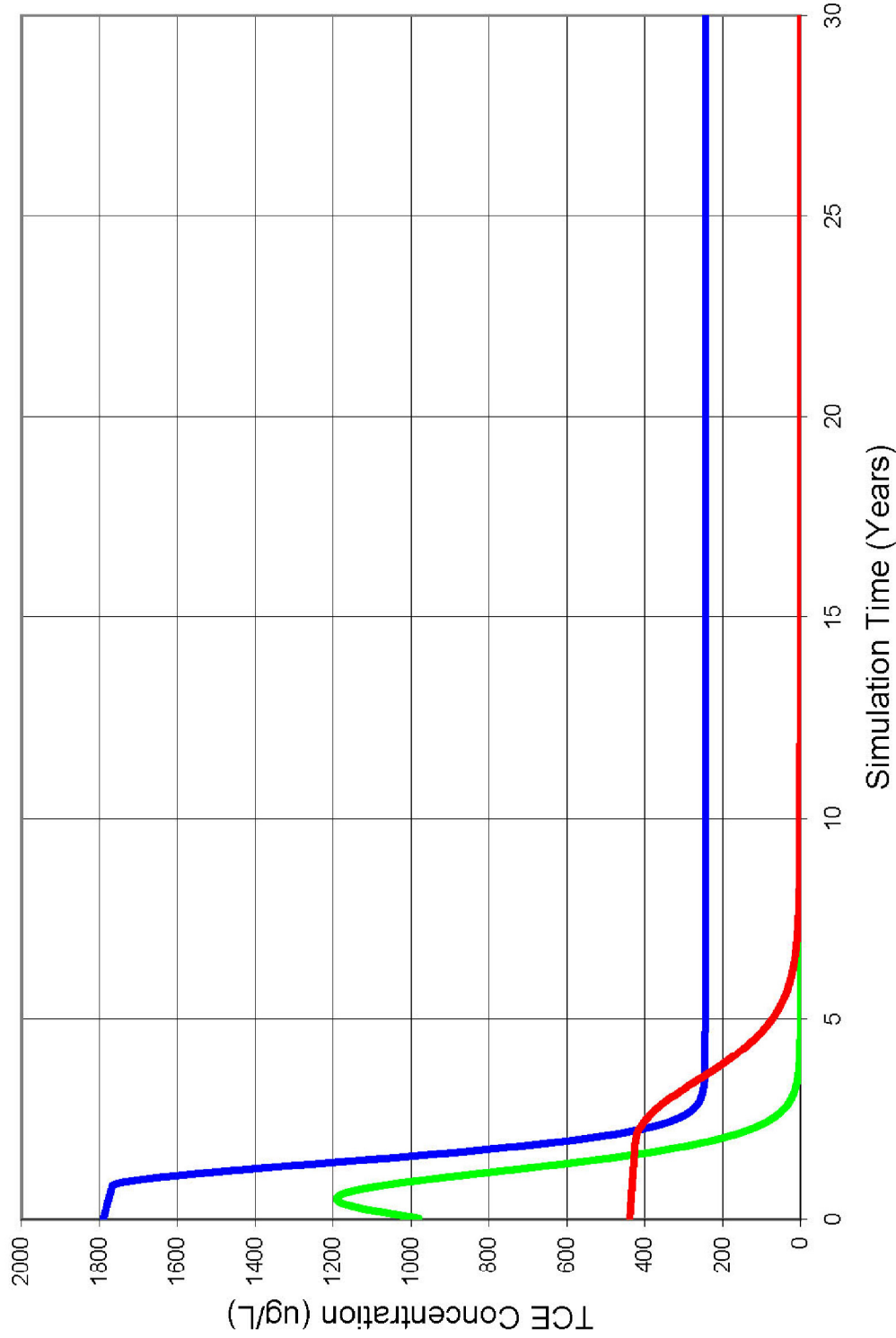
Figure I-25
Alternative 6
Pump and Treat in B-Zone, No Degradation
Modeled Concentration vs. Time at Selected B Zone Wells
Hookston Station
Pleasant Hill, California

ERM   *07/06*
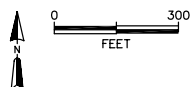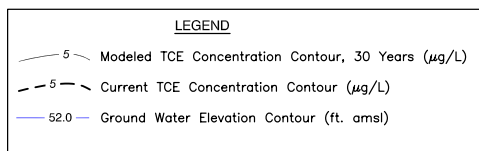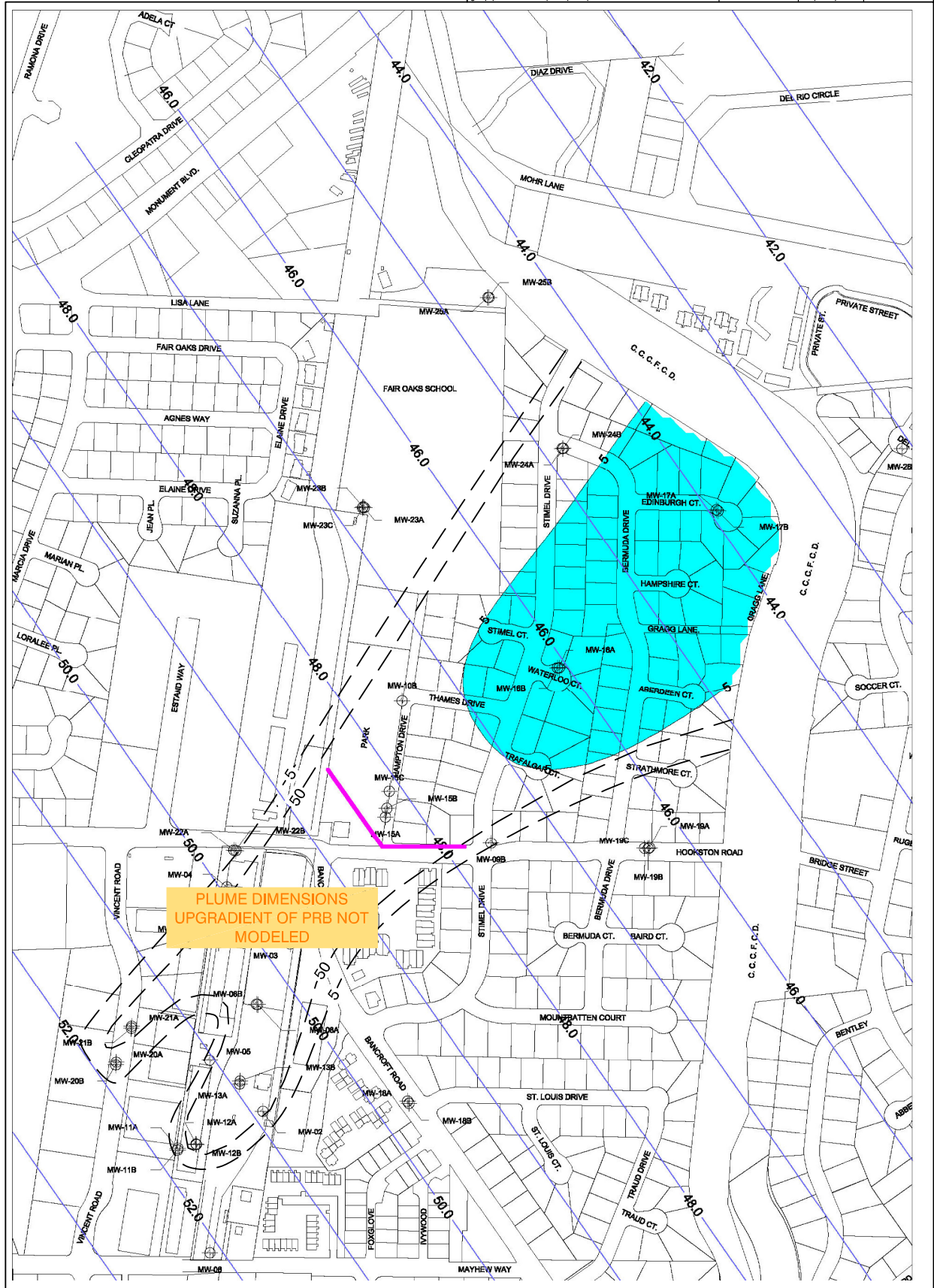
LEGEND

—5— Modeled TCE Concentration Contour, 30 Years (μg/L)

—52.0— Ground Water Elevation Contour (ft. amsl)

● Ground Water Extraction Well (Hypothetical)

0   300
FEET
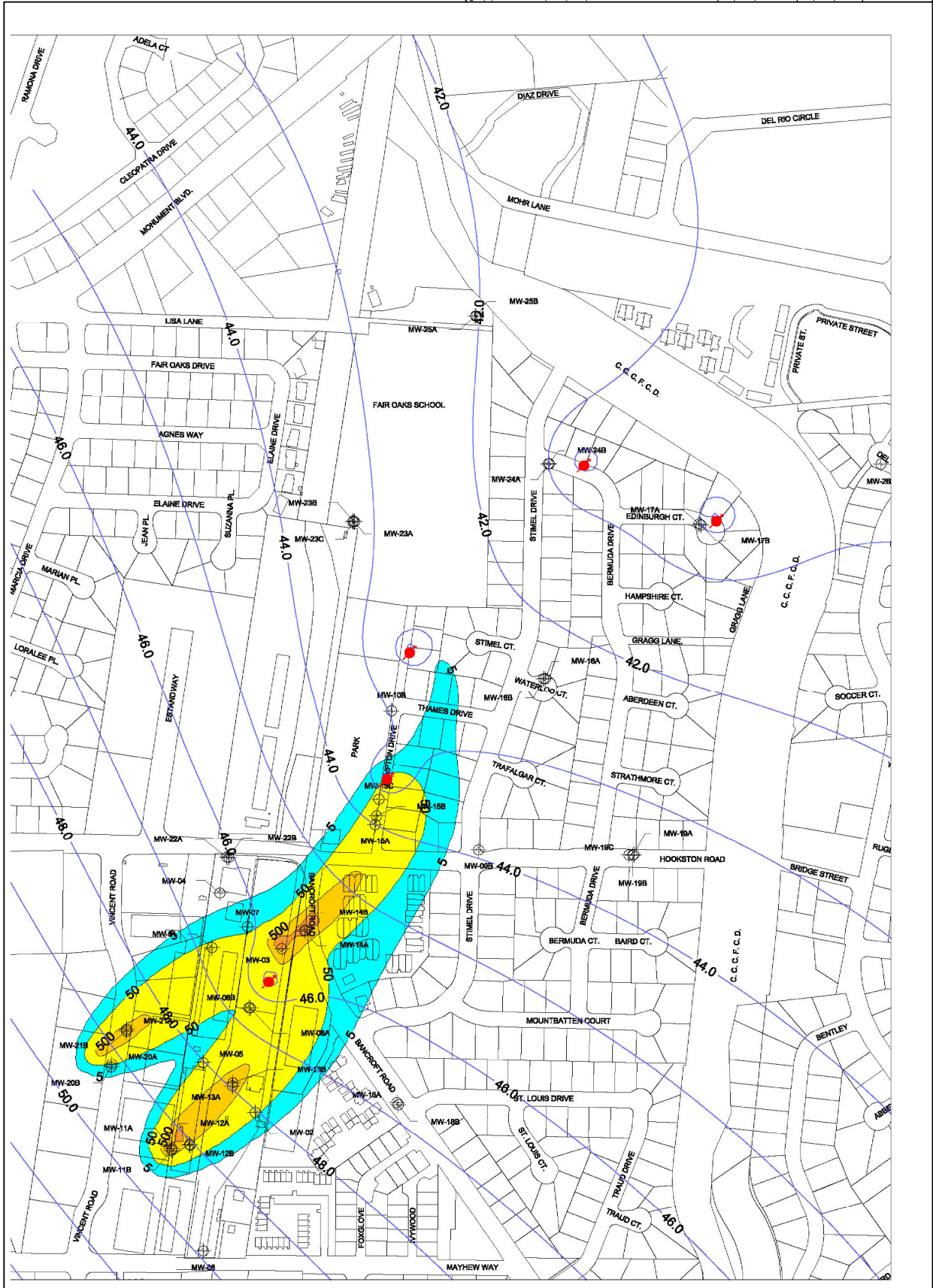
Figure I-26
Alternative 6
Pump and Treat in B-Zone, With Degradation
TCE Concentration Solution, Simulation Time 30 Years
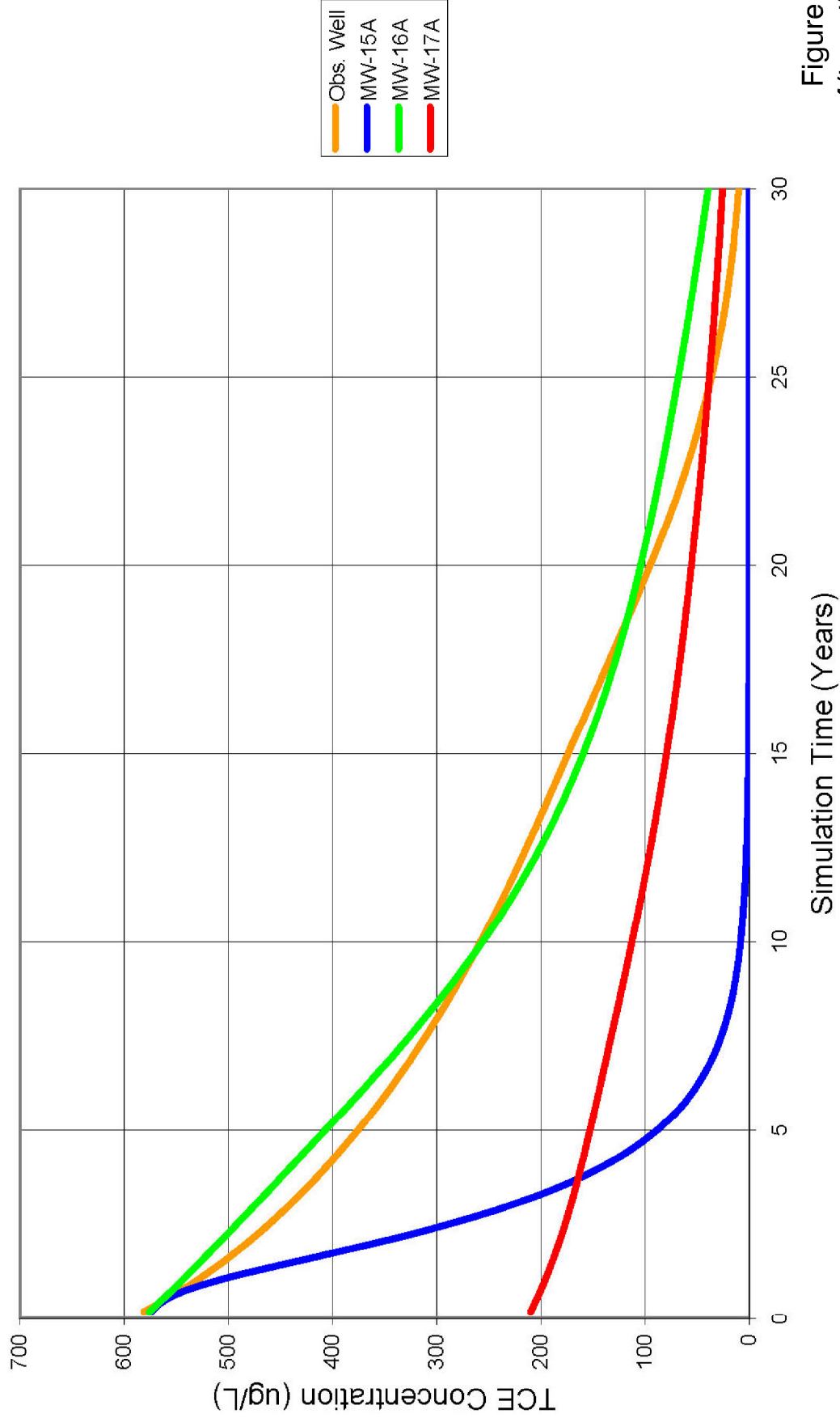*Hookston Station*
Pleasant Hill, California

ERM   *07/06*
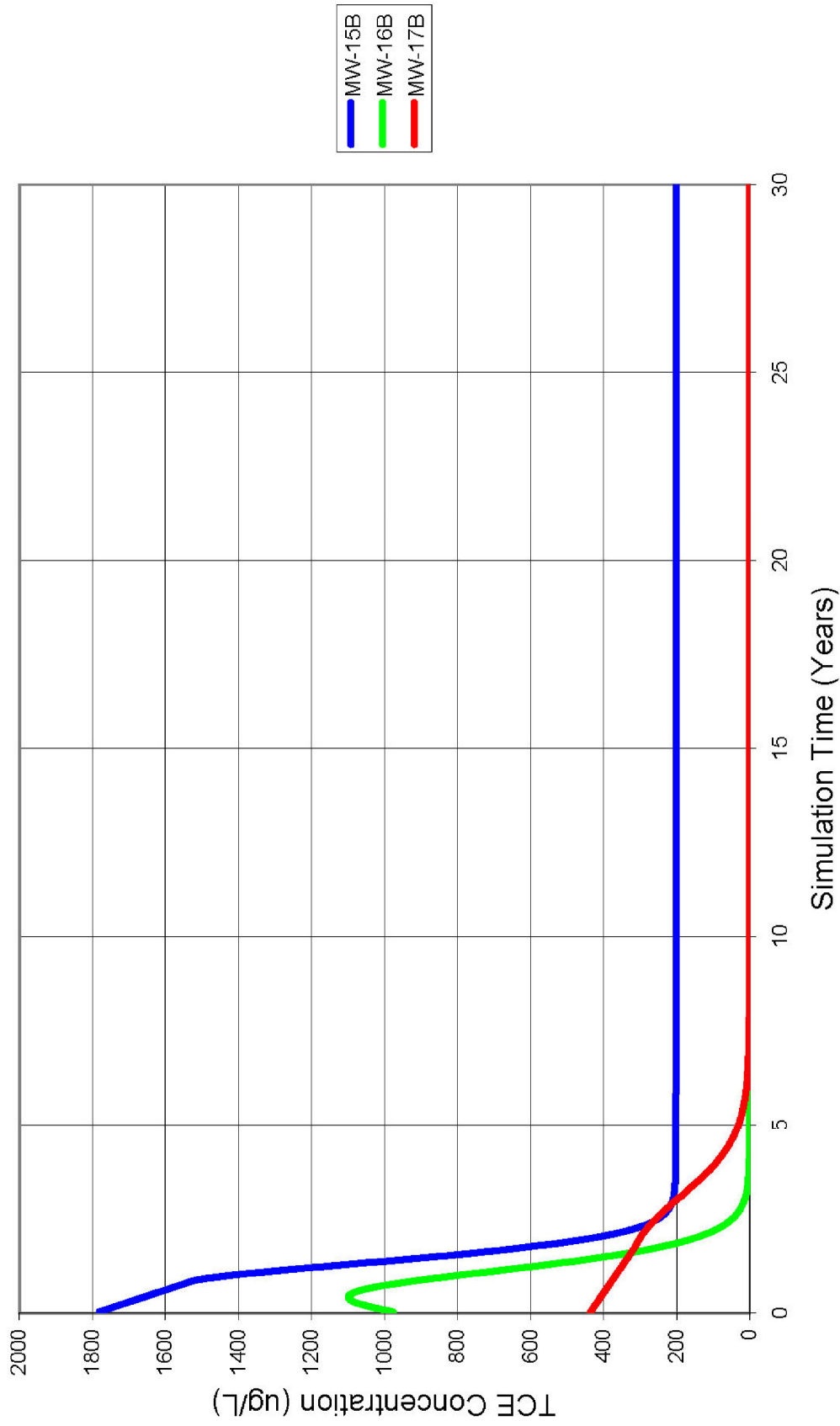
Figure I-27
Alternative 6
Pump and Treat in B Zone, With Degradation
Modeled Concentration vs. Time at Selected B-Zone Wells
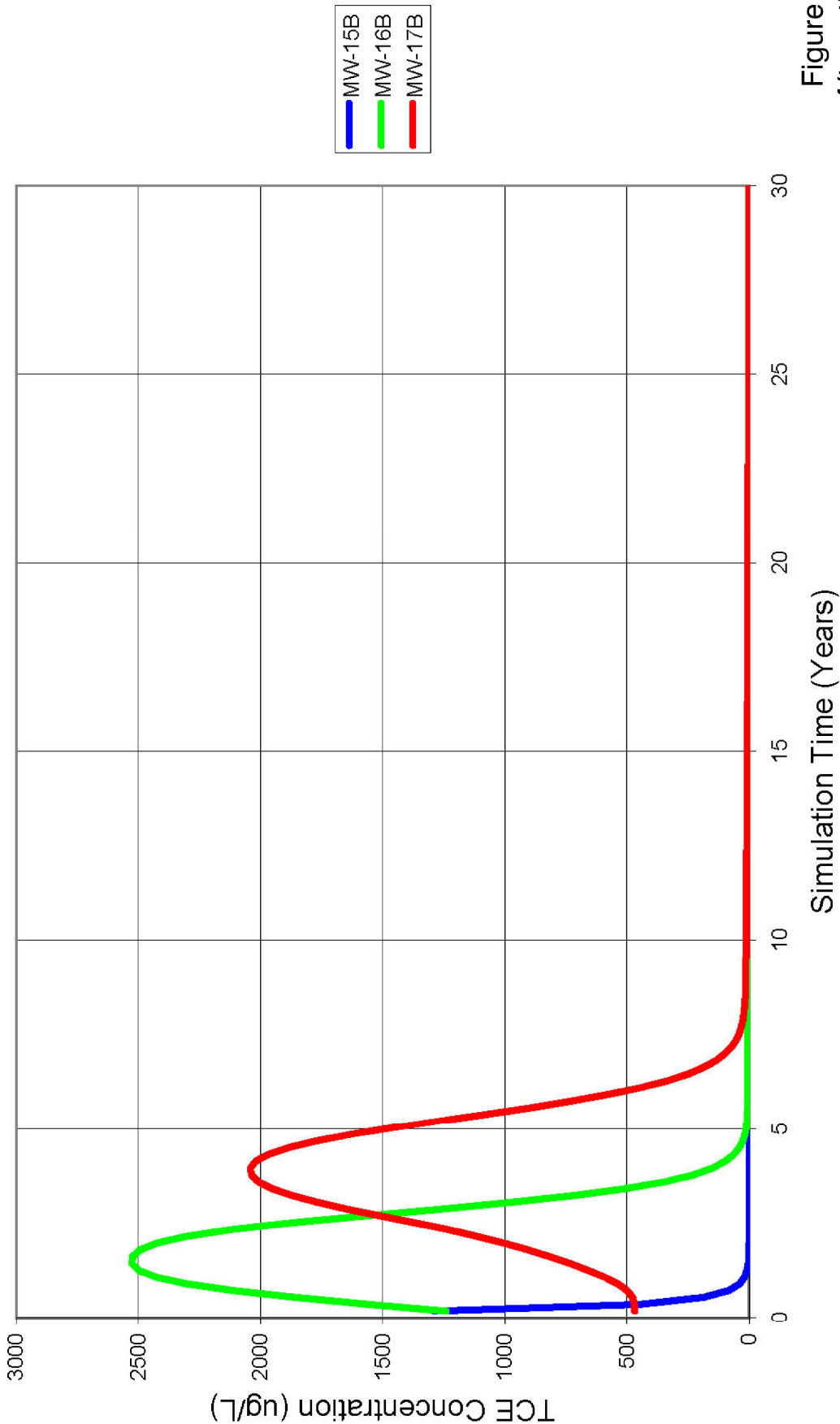*Hookston Station*
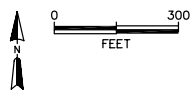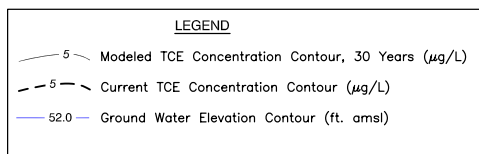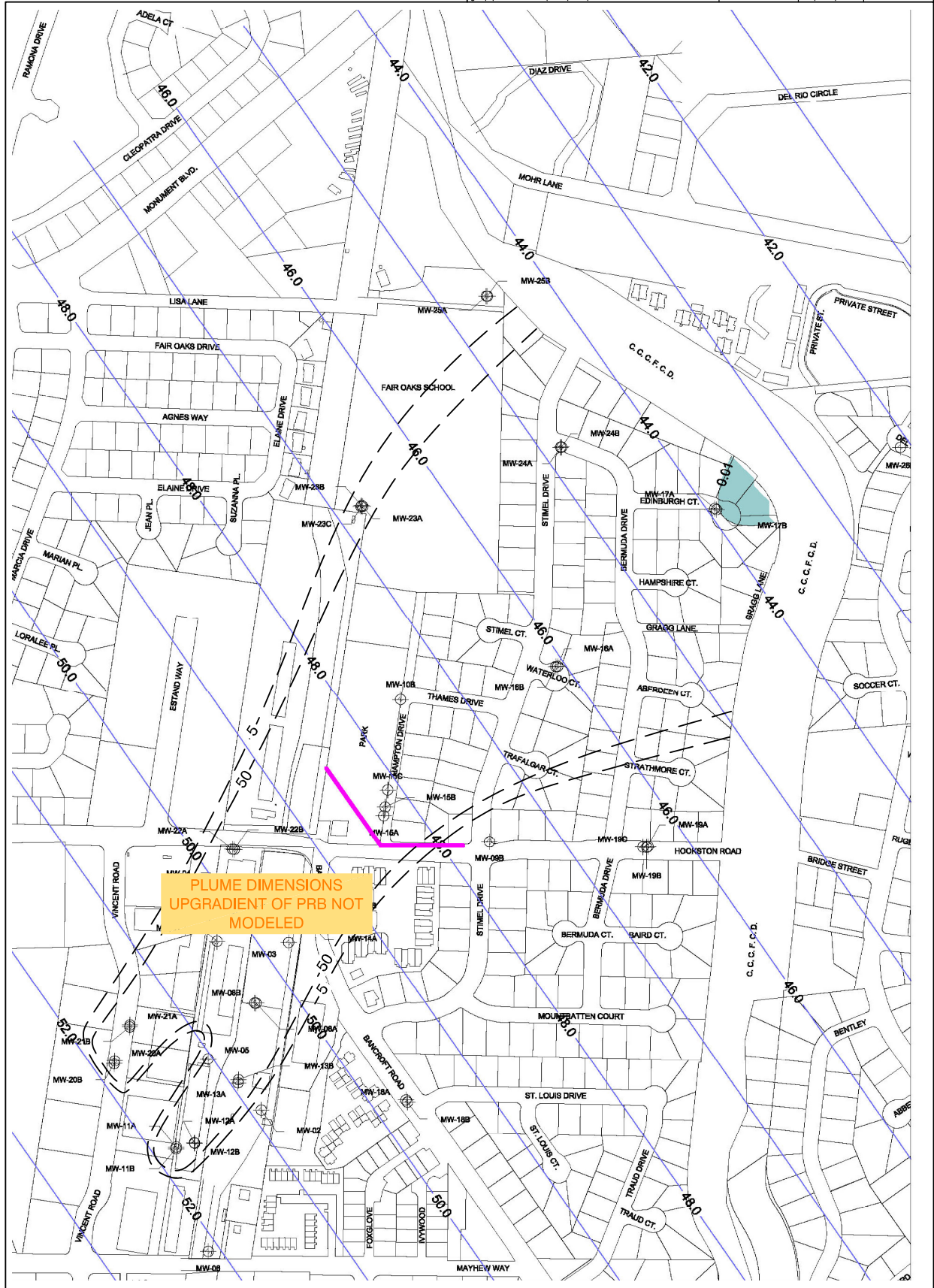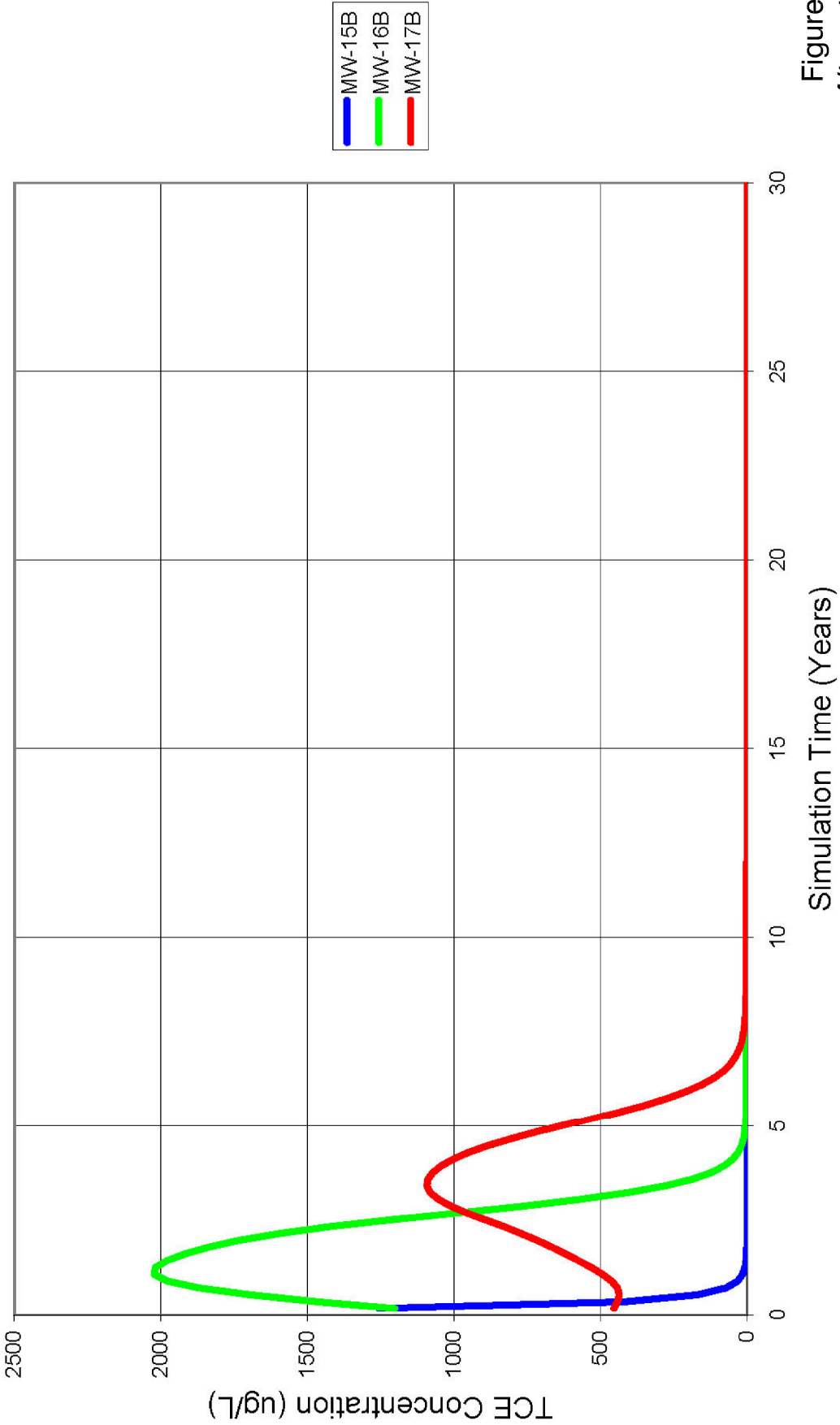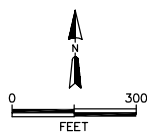*Pleasant Hill, California*

ERM   *07/06*

Legend:
MW-15B
MW-16B
MW-17B

Appendix J
Cost Estimates for Remedial
Alternatives

Remedial Alternative	Description	Direct and Indirect Capital Costs	Total O&M Costs (Undiscounted)	NPW of Total O&M Costs	Estimated Total Cost
Alternative 1	No Action	$0	$0	$0	**$0**
Alternative 2	Monitored Natural Attenuation - A-Zone and B-Zone Ground Water; Vapor Intrusion Prevention Systems; Private Well Removal.	$314,010	$4,584,460	$2,260,597	**$2,575,000**
Alternative 3	Enhanced Anaerobic Bioremediation - A-Zone Ground Water; In Situ Chemical Oxidation - B-Zone Ground Water ; Vapor Intrusion Prevention Systems; Private Well Removal.	$3,013,987	$3,000,155	$1,915,610	**$4,930,000**
Alternative 4	Zero-Valent Iron Permeable Reactive Barrier - A-Zone Ground Water; In Situ Chemical Oxidation - B-Zone Ground Water; Vapor Intrusion Prevention Systems; Private Well Removal.	$3,213,835	$3,483,641	$1,979,886	**$5,194,000**
Alternative 5	Zero-Valent Iron Permeable Reactive Barrier - A-Zone and B-Zone Ground Water; Vapor Intrusion Prevention Systems; Private Well Removal.	$7,067,510	$2,884,073	$1,670,940	**$8,739,000**
Alternative 6	Ground Water Extraction, Treatment, and Disposal - A-Zone and B-Zone Ground Water; Vapor Intrusion Prevention Systems; Private Well Removal	$1,900,257	$26,184,172	$10,905,844	**$12,807,000**

Notes:

(1) Present worth calculated using equal series present worth analysis where i = 7 %

Item	Value	
Indirect Costs		
Contractor Overhead & Profit	15%	TDC
Engineering and Construction Oversight	15%	TDC
Health and Safety Costs	3%	TDC
Project Management & Administration	10%	TDC
Replacement Costs	7%	TDC
Annual O&M Replacement Costs	7%	TDC
General Contingency	0%	Cap and O&M costs
Net Present Value Discount Rate	7%	
Net Present Value Multipliers for equal payment series	Years	Multiplier
	2	1.81
	3	2.62
	4	3.39
	5	4.10
	6	4.77
	7	5.39
	8	5.97
	9	6.52
	10	7.02
	15	9.11
	20	10.59
	25	11.65
	30	12.41
	35	12.95
	40	13.33
	45	13.61
	50	13.80

Well Installation

Well Installation Costs (incl. labor & expenses)	*On Parcel*	*Off Parcel*
A Zone Monitoring Well Detailed Costs		
Mobilization - daily	$250	$250
Drilling equipment and labor ($2,500/day x 1/3 day)	$833	$833
Well Materials ($12/ft x 45 ft)	$540	$540
Development equipment and labor ($1,350/day x 1/4 day)	$338	$338
Drums ($50/drum x 4)	$200	$200
Waste Disposal ($145/drum x 4) - nonhazardous	$580	$580
ERM Oversight ($85/hr x 4)	$340	$340
Support Vehicle ($105/day x 1/2)	$53	$53
Oversight Equipment and Supplies ($150/well)	$150	$150
Private Utility Locator ($140/hr x 1/2)	$70	$70
Well Permit ($358 per well)	$358	$358
Encroachment Permit	$0	$1,000
A Zone Monitoring Well Total Cost	$3,712	$4,712

Item	Value	
B Zone Monitoring Well Detailed Costs		
Mobilization - daily	$250	$250
Drilling equipment and labor ($2,500/day x 1/2 day)	$1,250	$1,250
Well Materials ($12/ft x 70 ft)	$840	$840
Development equipment and labor ($1,350/day x 1/4 day)	$338	$338
Drums ($50/drum x 7)	$350	$350
Waste Disposal ($145/drum x 7) - nonhazardous	$1,015	$1,015
ERM Oversight ($85/hr x 5)	$425	$425
Support Vehicle ($105/day x 1/2)	$53	$53
Oversight Equipment and Supplies ($150/well)	$150	$150
Private Utility Locator ($140/hr x 1/2)	$70	$70
Well Permit ($358 per well)	$358	$358
Encroachment Permit	$0	$1,000
B Zone Monitoring Well Total Cost	**$5,099**	**$6,099**
A Zone Extraction Well Detailed Cost		
Mobilization - daily	$250	$250
Drilling equipment and labor ($2,500/day x 1/3 day)	$833	$833
Well Materials ($12/ft x 45 ft)	$180	$180
Well vault and well head equipment	$3,500	$3,500
Development equipment and labor ($1,350/day x 1/4 day)	$338	$338
Drums ($50/drum x 4)	$200	$200
Waste Disposal ($145/drum x 4) - nonhazardous	$580	$580
ERM Oversight ($85/hr x 8)	$680	$680
Support Vehicle ($105/day x 1)	$105	$105
Oversight Equipment and Supplies ($150/well)	$150	$150
Private Utility Locator ($140/hr x 1/2)	$70	$70
Well Permit ($358 per well)	$358	$358
Encroachment Permit	$0	$1,000
A Zone Extraction Well Total Cost	**$7,244**	**$8,244**
B Zone Extraction Well Detailed Cost		
Mobilization - daily	$250	$250
Drilling equipment and labor ($2,500/day x 1/2 day)	$1,250	$1,250
Well Materials ($19/ft x 70 ft)	$1,330	$1,330
Well vault and well head equipment	$3,500	$3,500
Development equipment and labor ($1,350/day x 1/4 day)	$338	$338
Drums ($50/drum x 7)	$350	$350
Waste Disposal ($145/drum x 7) - nonhazardous	$1,015	$1,015
ERM Oversight ($85/hr x 12)	$1,020	$1,020
Support Vehicle ($105/day x 1 1/2)	$158	$158
Oversight Equipment and Supplies ($150/well)	$150	$150
Private Utility Locator ($140/hr x 1/2)	$70	$70
Well Permit ($358 per well)	$358	$358
Encroachment Permit	$0	$1,000
B Zone Extraction Well Total Cost	**$9,789**	**$10,789**

Item	Value	
A Zone Injection Well Cost (Same as extraction well)	$7,244	$8,244
B Zone Injection Well Cost (Same as extraction well)	$9,789	$10,789

Well Sampling	*On Parcel*	*Off Parcel*
Daily Sampling Labor (10 hours 2 technicians @ $85/hr)	$1,700	$1,700
Daily Vehicle Rental	$105	$105
Daily Water Quality Meter Rental	$100	$100
Daily Water Level Indicator Rental	$25	$25
Daily sample pump and equipment rental	$50	$50
Supplies (tubing, gloves, etc.) - est. daily	$150	$150
Daily Subtotal	$2,130	$2,130
Number of wells sampled per day	10	10
Total Well Sampling Costs per well	$213	$213

Laboratory Costs

VOCs - Air (TO-15, including Summa rental)	$210	
VOCs - GW (8260)	$75	
MNA Parameters	$244	
EPA 8000 (Methane, Ethane, Ethene)		$153.00
EPA 6020 Metals (diss. Fe, Mn)		$32.00
EPA 300.0 (chloride, sulfate, nitrate)		$30.00
EPA 9060 (TOC)		$18.00
EPA 310.1 alkalinity		$10.80
% of Wells for MNA Samples	50%	
% QA/QC Samples - VOCs	30%	
% QA/QC Samples - MNA Parameters	15%	

Injection Costs

On Parcel Bioremediation Fluid Direct-Push Injection (A-Zone or B-Zone)

Daily Direct-Push Drilling Crew	$2,000
Daily Injection Equipment Rental	$500
Daily Vehicle Rental	$105
Daily Oversight Labor (10 hours 2 technicians @ $85/hr)	$1,700
Daily Subtotal	$4,305
Number of injection points per day	5
Total Injection Costs per location	$861

Bioremediation Fluid Cost (emulsified soybean oil)	$1.25

On Parcel Oxidant Fluid Direct-Push Injection (B-zone)

Daily Direct-Push Drilling Crew	$2,000
Daily Injection Equipment Rental	$500
Daily Vehicle Rental	$105
Daily Oversight Labor (10 hours 2 technicians @ $85/hr)	$1,700

Item	Value
Daily Subtotal	$4,305
Number of injection points per day	10
Total Injection Costs per location	$431
Oxidant Cost (Potassium Permanganate)	$1.75
Off Parcel Bioremediation Fluid Injection - Injection Wells	
Daily Direct-Push Drilling Crew	$2,000
Daily Injection Equipment Rental	$500
Daily Vehicle Rental	$105
Daily Oversight Labor (10 hours 2 technicians @ $85/hr)	$1,700
Daily Subtotal	$4,305
Number of injection points per day	5
Total Injection Costs per location	$861

DESCRIPTION	QUANTITY		COST	
	Number	**Unit**	**Unit Cost**	**Total Cost**
DIRECT CAPITAL COSTS				
Well Construction				
Work Plan	1	ea.	$20,000	$20,000
On Parcel A Zone Monitoring Well	5	ea.	$3,712	$18,560
Off Parcel A Zone Monitoring Well	5	ea.	$4,712	$23,560
On Parcel B Zone Monitoring Well	5	ea.	$5,099	$25,495
Off Parcel B Zone Monitoring Well	5	ea.	$6,099	$30,495
Surveying	1	day	$1,500	$1,500
SUBTOTAL				**$119,610**
Vapor Intrusion Prevention Systems				
Vapor intrusion prevention system installed in homes within the area of observed indoor air impacts, including barrier with under-barrier vapor extraction and treatment (20 homes)	20	homes	$5,000.00	$100,000
SUBTOTAL				**$100,000**
TOTAL DIRECT CAPITAL COSTS				*$219,610*
INDIRECT CAPITAL COSTS				
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$32,942	$32,942
Engineering and Construction Oversight (15% Total Direct Costs)	1	LS	$32,942	$32,942
Health and Safety Costs (3% Total Direct Costs)	1	LS	$6,588	$6,588
Project Management & Administration (10% Total Direct Costs)	1	LS	$21,961	$21,961
TOTAL INDIRECT CAPITAL COSTS				**$94,400**
TOTAL CAPITAL COSTS (Direct and Indirect)				*$314,010*
O & M COSTS				
Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	60	wells	$213	$12,780
Ground Water Analysis - VOCs (60 wells + 30% QA/QC)	78	samples	$75	$5,850
Ground Water Analysis - MNA Parameters (30 wells)	30	samples	$244	$7,314
Reporting	1	LS	$15,000	$15,000
SUBTOTAL				**$40,944**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$6,142	$6,142
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,228	$1,228
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,094	$4,094
SUBTOTAL				**$11,464**
Total Costs Per Event				**$52,408**
Annual O&M Cost (Year 1-5, quarterly sampling)				**$209,633**
Annual O&M Cost (Year 6-10, semiannual sampling)				**$104,817**
Annual O&M Cost (Year 11-30, annual sampling)				**$52,408**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$2,620,416**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$1,448,200**
Vapor Intrusion Prevention Systems Maintenance				
Air Monitoring (VOC TO-15 samples)	20	samples	$210	$4,200
Electricity (vapor extraction systems, 2 HP fans, Continuous operation)	12	month	$2,831	$33,968
Systems Inspection	20	homes	$350	$7,000
Systems Maintence and Repair	1	LS	$2,500	$2,500
Reporting	1	LS	$5,000	$5,000
SUBTOTAL				**$48,468**

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Replacement Costs (7% Total Direct Costs)	1	LS	$3,393	$3,393
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$7,270	$7,270
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,454	$1,454
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,847	$4,847
SUBTOTAL				**$17,000**
Annual O&M Costs (year 1-30)				**$65,468**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$1,964,044**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$812,397**
TOTAL UNDISCOUNTED O&M COSTS				**$4,584,460**
TOTAL NET PRESENT WORTH O&M COSTS				**$2,260,597**
TOTAL CAPITAL AND O & M COSTS				*$2,574,607*
General Contingency (0% of Total Capital and O&M Costs)				*$0*
TOTAL COST OF ALTERNATIVE (PRESENT WORTH)				*$2,575,000*

Notes:

(1) Present worth calculated using equal series present worth analysis where i = 7 %

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
DIRECT CAPITAL COSTS				
Preparation and Well Construction				
Design/Work Plan	1	ea.	$100,000	$100,000
On Parcel A Zone Monitoring Well	5	ea.	$3,712	$18,560
Off Parcel A Zone Monitoring Well	5	ea.	$4,712	$23,560
On Parcel B Zone Monitoring Well	5	ea.	$5,099	$25,495
Off Parcel B Zone Monitoring Well	5	ea.	$6,099	$30,495
Off-Site A Zone Injection Wells	8	ea.	$8,244	$65,952
Surveying	1	day	$1,500	$1,500
SUBTOTAL				**$265,562**
A-Zone Bioremediation Injection				
On-Site A-Zone Direct-Push Injection of Bioremediation ammendment - 15 to 25 feet bgs (120,000 square feet, 20' on center rows with 60' spacing, 100 locations and 3 applications)	300	Injection	$861	$258,300
On-Site A-Zone Ammendment (100 locations, 1780 pounds oil emulsion per location (220 gallons at 8.1 pounds per gallons, 3 applications)	534,000	lbs.	$1.25	$667,500
Off-Site A-Zone Injection of Bioremediation ammendment - 15 to 30 feet bgs (8 injection wells and 10 applications)	80	Injection	$2,000	$160,000
Off-Site A-Zone Ammendment (8 injection wells, 3500 pounds oil emulsion per well [10 annual applications])	280,000	lbs.	$1.25	$350,000
SUBTOTAL				**$1,435,800**
B-Zone Oxidant Injection				
B-Zone Direct-Push Injection of Potassium Permanganate - 45 to 60 feet bgs (60,000 square feet, 150 locations and 3 applications)	450	Injection	$431	$193,725
Potassium Permanganate (450 Zone B injections with 560 gallons of solution containing 143 lbs per injection)	64,350	lbs.	$1.75	$112,600
SUBTOTAL				**$306,325**
Vapor Intrusion Prevention Systems				
Vapor intrusion prevention system installed in homes within the area of observed indoor air impacts, including barrier with under-barrier vapor extraction and treatment (20 homes)	20	homes	$5,000.00	$100,000
SUBTOTAL				**$100,000**
TOTAL DIRECT CAPITAL COSTS				*$2,107,687*
INDIRECT CAPITAL COSTS				
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$316,153	$316,153
Engineering and Construction Oversight (15% Total Direct Costs)	1	LS	$316,153	$316,153
Health and Safety Costs (3% Total Direct Costs)	1	LS	$63,231	$63,231
Project Management & Administration (10% Total Direct Costs)	1	LS	$210,769	$210,769
TOTAL INDIRECT CAPITAL COSTS				**$906,300**
TOTAL CAPITAL COSTS (Direct and Indirect)				*$3,013,987*
O & M COSTS				
Hookston Station Parcel A-Zone Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	15	wells	$213	$3,195
Ground Water Analysis - VOCs (15 wells + 30% QA/QC)	20	samples	$75	$1,500
Ground Water Analysis - MNA Parameters (8 wells)	8	samples	$244	$1,950
Reporting	1	LS	$5,000	$5,000
SUBTOTAL				**$11,645**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$1,747	$1,747

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Health and Safety Costs (3% Total Direct Costs)	1	LS	$349	$349
Project Management & Administration (10% Total Direct Costs)	1	LS	$1,165	$1,165
SUBTOTAL				**$3,300**
Total Costs Per Event				**$14,945**
Annual O&M Cost (Year 1-5, quarterly sampling)				**$59,782**
Annual O&M Cost (Year 6-10, semiannual sampling)				**$29,891**
SUBTOTAL UNDISCOUNTED O&M COSTS (10 years)				**$448,362**
SUBTOTAL NET PRESENT WORTH O&M COSTS (10 years) (1)				**$332,499**

Downgradient Study Area A-Zone Ground Water Monitoring Cost Per Event

DESCRIPTION	QUANTITY		COST	
Well Sampling Labor and Equipment	15	wells	$213	$3,195
Ground Water Analysis - VOCs (15 wells + 30% QA/QC)	20	samples	$75	$1,500
Ground Water Analysis - MNA Parameters (8 wells)	8	samples	$244	$1,950
Reporting	1	LS	$7,500	$7,500
SUBTOTAL				**$14,145**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$2,122	$2,122
Health and Safety Costs (3% Total Direct Costs)	1	LS	$424	$424
Project Management & Administration (10% Total Direct Costs)	1	LS	$1,415	$1,415
SUBTOTAL				**$4,000**
Total Costs Per Event				**$18,145**
Annual O&M Cost (Year 1-5, quarterly sampling)				**$72,582**
Annual O&M Cost (Year 6-10, semiannual sampling)				**$36,291**
Annual O&M Cost (Year 11-30, annual sampling)				**$18,145**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$725,816**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$501,412**

B-Zone Ground Water Monitoring Cost Per Event

DESCRIPTION	QUANTITY		COST	
Well Sampling Labor and Equipment	30	wells	$213	$6,390
Ground Water Analysis - VOCs (30 wells + 30% QA/QC)	39	samples	$75	$2,925
Ground Water Analysis - MNA Parameters (15 wells)	15	samples	$244	$3,657
Reporting	1	LS	$12,500	$12,500
SUBTOTAL				**$25,472**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$3,821	$3,821
Health and Safety Costs (3% Total Direct Costs)	1	LS	$764	$764
Project Management & Administration (10% Total Direct Costs)	1	LS	$2,547	$2,547
SUBTOTAL				**$7,100**
Total Costs Per Event				**$32,572**
Annual O&M Cost (Year 1-3, quarterly sampling)				**$130,288**
Annual O&M Cost (Year 4-8, semiannual sampling)				**$65,144**
Annual O&M Cost (Year 9-30, annual sampling)				**$32,572**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$1,433,168**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$769,643**

Vapor Intrusion Prevention Systems Maintenance

DESCRIPTION	QUANTITY		COST	
Air Monitoring (VOC TO-15 samples)	20	samples	$210	$4,200
Electricity (vapor extraction systems, 2 HP fans, Continuous operation)	12	month	$2,831	$33,968
Systems Inspection	20	homes	$350	$7,000
Systems Maintence and Repair	1	LS	$2,500	$2,500
Reporting	1	LS	$5,000	$5,000

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
SUBTOTAL				$48,468
Replacement Costs (7% Total Direct Costs)	1	LS	$3,393	$3,393
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$7,270	$7,270
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,454	$1,454
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,847	$4,847
SUBTOTAL				$17,000
Annual O&M Costs (year 1-6)				$65,468
SUBTOTAL UNDISCOUNTED O&M COSTS (6 years)				$392,809
SUBTOTAL NET PRESENT WORTH O&M COSTS (6 years) (1)				$312,056
TOTAL UNDISCOUNTED O&M COSTS				$3,000,155
NET PRESENT WORTH OF TOTAL O&M COSTS				$1,915,610
TOTAL CAPITAL AND O & M COSTS				$4,929,597
General Contingency (0% of Total Capital and O&M Costs)				$0
TOTAL COST OF ALTERNATIVE (PRESENT WORTH)				$4,930,000

Notes:
(1) Present worth calculated using equal series present worth analysis where i = 7 %

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
DIRECT CAPITAL COSTS				
Preparation and Well Construction				
Design/Work Plan	1	ea.	$100,000	$100,000
On Parcel A Zone Monitoring Well	5	ea.	$3,712	$18,560
Off Parcel A Zone Monitoring Well	5	ea.	$4,712	$23,560
On Parcel B Zone Monitoring Well	5	ea.	$5,099	$25,495
Off Parcel B Zone Monitoring Well	5	ea.	$6,099	$30,495
Surveying	2	day	$1,500	$3,000
SUBTOTAL				**$201,110**
A-Zone PRB Construction				
Column reductive dechlorination test	1	ea.	$25,000	$25,000
Hydraulic testing	1	ea.	$30,000.00	$30,000
Mobilization/Site Prep	1	LS	$160,000.00	$160,000
PRB Installation (Trenched and Placed in Zone A from 15'-35' bgs)	10000	SF	$139.00	$1,390,000
Site Restoration	1	LS	$35,000.00	$35,000
SUBTOTAL				**$1,640,000**
B-Zone Oxidant Injection				
Zone B Direct-Push Injection of Potassium Permanganate - 45 to 60 feet bgs (60,000 square feet, 150 locations and 3 applications)	450	Injection	$431	$193,725
Potassium Permanganate (450 Zone B injections with 560 gallons of solution containing 143 lbs per injection)	64,350	lbs.	$1.75	$112,600
SUBTOTAL				**$306,325**
Vapor Intrusion Prevention Systems				
Vapor intrusion prevention system installed in homes within the area of observed indoor air impacts, including barrier with under-barrier vapor extraction and treatment (20 homes)	20	homes	$5,000.00	$100,000
SUBTOTAL				**$100,000**
TOTAL DIRECT CAPITAL COSTS				**$2,247,435**
INDIRECT CAPITAL COSTS				
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$337,115	$337,115
Engineering and Construction Oversight (15% Total Direct Costs)	1	LS	$337,115	$337,115
Health and Safety Costs (3% Total Direct Costs)	1	LS	$67,423	$67,423
Project Management & Administration (10% Total Direct Costs)	1	LS	$224,744	$224,744
TOTAL INDIRECT CAPITAL COSTS				**$966,400**
TOTAL CAPITAL COSTS (Direct and Indirect)				**$3,213,835**
O & M COSTS				
A-Zone Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	30	wells	$213	$6,390
Ground Water Analysis - VOCs (30 wells + 30% QA/QC)	39	samples	$75	$2,925
Ground Water Analysis - MNA Parameters (15 wells)	15	samples	$244	$3,657
Reporting	1	LS	$15,000	$15,000
SUBTOTAL				**$27,972**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$4,196	$4,196
Health and Safety Costs (3% Total Direct Costs)	1	LS	$839	$839
Project Management & Administration (10% Total Direct Costs)	1	LS	$2,797	$2,797
SUBTOTAL				**$7,800**

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Total Costs Per Event				**$35,772**
Annual O&M Cost (Year 1-5, quarterly sampling)				**$143,088**
Annual O&M Cost (Year 6-10, semiannual sampling)				**$71,544**
Annual O&M Cost (Year 11-30, annual sampling)				**$35,772**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$1,788,600**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$988,488**
Off-Site B-Zone Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	30	wells	$213	$6,390
Ground Water Analysis - VOCs (30 wells + 30% QA/QC)	39	samples	$75	$2,925
Ground Water Analysis - MNA Parameters (15 wells)	15	samples	$244	$3,657
Reporting	1	LS	$12,500	$12,500
SUBTOTAL				**$25,472**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$3,821	$3,821
Health and Safety Costs (3% Total Direct Costs)	1	LS	$764	$764
Project Management & Administration (10% Total Direct Costs)	1	LS	$2,547	$2,547
SUBTOTAL				**$7,100**
Total Costs Per Event				**$32,572**
Annual O&M Cost (Year 1-3, quarterly sampling)				**$130,288**
Annual O&M Cost (Year 4-8, semiannual sampling)				**$65,144**
Annual O&M Cost (Year 9-30, annual sampling)				**$32,572**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$1,433,168**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$769,643**
Vapor Intrusion Prevention Systems Maintenance				
Air Monitoring (VOC TO-15 samples)	20	samples	$210	$4,200
Electricity (vapor extraction systems, 2 HP fans, Continuous operation)	12	month	$2,831	$33,968
Systems Inspection	20	homes	$350	$7,000
Systems Maintence and Repair	1	LS	$2,500	$2,500
Reporting	1	LS	$5,000	$5,000
SUBTOTAL				**$48,468**
Replacement Costs (7% Total Direct Costs)	1	LS	$3,393	$3,393
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$7,270	$7,270
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,454	$1,454
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,847	$4,847
SUBTOTAL				**$17,000**
Annual O&M Costs (year 1-4)				**$65,468**
SUBTOTAL UNDISCOUNTED O&M COSTS (4 years)				**$261,873**
SUBTOTAL NET PRESENT WORTH O&M COSTS (4 years) (1)				**$221,754**
TOTAL UNDISCOUNTED O&M COSTS				*$3,483,641*
NET PRESENT WORTH OF TOTAL O&M COSTS				*$1,979,886*
TOTAL CAPITAL AND O & M COSTS				*$5,193,721*
General Contingency (0% of Total Capital and O&M Costs)				*$0*
TOTAL COST OF ALTERNATIVE (PRESENT WORTH)				*$5,194,000*

Notes:

(1) Present worth calculated using equal series present worth analysis where i = 7 %

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
DIRECT CAPITAL COSTS				
Preparation and Well Construction				
Design/Work Plan	1	ea.	$100,000	$100,000
On Parcel A Zone Monitoring Well	5	ea.	$3,712	$18,560
Off Parcel A Zone Monitoring Well	5	ea.	$4,712	$23,560
On Parcel B Zone Monitoring Well	5	ea.	$5,099	$25,495
Off Parcel B Zone Monitoring Well	5	ea.	$6,099	$30,495
Surveying	2	day	$1,500	$3,000
SUBTOTAL				**$201,110**
A-Zone PRB Construction				
Column reductive dechlorination test	1	ea.	$25,000	$25,000
Hydraulic testing	1	ea.	$30,000.00	$30,000
PRB Installation (Injected in Zone A from 15'-35' bgs)	480	ft	$3,615.00	$1,735,200
SUBTOTAL				**$1,790,200**
B-Zone PRB Construction				
Column reductive dechlorination test	1	ea.	$25,000	$25,000
Hydraulic testing	1	ea.	$30,000.00	$30,000
PRB Installation (Injected in Zone B from 40'-70' bgs)	480	ft	$5,825.00	$2,796,000
SUBTOTAL				**$2,851,000**
Vapor Intrusion Prevention Systems				
Vapor intrusion prevention system installed in homes within the area of observed indoor air impacts, including barrier with under-barrier vapor extraction and treatment (20 homes)	20	homes	$5,000.00	$100,000
SUBTOTAL				**$100,000**
TOTAL DIRECT CAPITAL COSTS				*$4,942,310*
INDIRECT CAPITAL COSTS				
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$741,347	$741,347
Engineering and Construction Oversight (15% Total Direct Costs)	1	LS	$741,347	$741,347
Health and Safety Costs (3% Total Direct Costs)	1	LS	$148,269	$148,269
Project Management & Administration (10% Total Direct Costs)	1	LS	$494,231	$494,231
TOTAL INDIRECT CAPITAL COSTS				**$2,125,200**
TOTAL CAPITAL COSTS (Direct and Indirect)				*$7,067,510*
O & M COSTS				
A-Zone and B-Zone Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	60	wells	$213	$12,780
Ground Water Analysis - VOCs (60 wells + 30% QA/QC)	78	samples	$75	$5,850
Ground Water Analysis - MNA Parameters (30 wells)	30	samples	$244	$7,314
Reporting	1	LS	$15,000	$15,000
SUBTOTAL				**$40,944**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$6,142	$6,142
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,228	$1,228
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,094	$4,094
SUBTOTAL				**$11,500**
Total Costs Per Event				**$52,444**

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Annual O&M Cost (Year 1-5, quarterly sampling)				**$209,776**
Annual O&M Cost (Year 6-10, semiannual sampling)				**$104,888**
Annual O&M Cost (Year 11-30, annual sampling)				**$52,444**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$2,622,200**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$1,449,186**
Vapor Intrusion Prevention Systems Maintenance				
Air Monitoring (VOC TO-15 samples)	20	samples	$210	$4,200
Electricity (vapor extraction systems, 2 HP fans, Continuous operation)	12	month	$2,831	$33,968
Systems Inspection	20	homes	$350	$7,000
Systems Maintence and Repair	1	LS	$2,500	$2,500
Reporting	1	LS	$5,000	$5,000
SUBTOTAL				**$48,468**
Replacement Costs (7% Total Direct Costs)	1	LS	$3,393	$3,393
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$7,270	$7,270
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,454	$1,454
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,847	$4,847
SUBTOTAL				**$17,000**
Annual O&M Costs (year 1-4)				**$65,468**
SUBTOTAL UNDISCOUNTED O&M COSTS (4 years)				**$261,873**
SUBTOTAL NET PRESENT WORTH O&M COSTS (4 years) (1)				**$221,754**
TOTAL UNDISCOUNTED O&M COSTS				*$2,884,073*
NET PRESENT WORTH OF TOTAL O&M COSTS				*$1,670,940*
TOTAL CAPITAL AND O & M COSTS				*$8,738,450*
General Contingency (0% of Total Capital and O&M Costs)				*$0*
TOTAL COST OF ALTERNATIVE (PRESENT WORTH)				*$8,739,000*

Notes:
(1) Present worth calculated using equal series present worth analysis where i = 7 %

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
DIRECT CAPITAL COSTS				
Preparation Work/Construction				
Work Plan (Design and Permitting)	1	ea.	$100,000	$100,000
AQMD Permitting	1	LS	$10,000	$10,000
On Parcel A Zone Monitoring Well	5	ea.	$3,712	$18,560
Off Parcel A Zone Monitoring Well	5	ea.	$4,712	$23,560
On Parcel B Zone Monitoring Well	5	ea.	$5,099	$25,495
Off Parcel B Zone Monitoring Well	5	ea.	$6,099	$30,495
On Parcel A Zone Extraction Wells	6	ea.	$7,244	$43,464
On Parcel B Zone Extraction Wells	1	ea.	$9,789	$9,789
Off Parcel A Zone Extraction Wells	9	ea.	$8,244	$74,196
OffParcel B Zone Extraction Wells	4	ea.	$10,789	$43,154
On Parcel Trenching	1000	ft	$50.00	$50,000
Off parcel Trenching	3500	ft	$75.00	$262,500
A-Zone Piping (2" pv c)	2550	ft	$3.20	$8,160
B-Zone Piping (4" pv c)	2800	ft	$7.38	$20,664
Conduit	3500	ft	$11.92	$41,720
Pad and treatment building	1	ea.	$50,000.00	$50,000
Surveying	2	day	$1,500	$3,000
SUBTOTAL				**$814,757**
Equipment				
Tray Air Stripping System	1	ea.	$97,868	$97,868
A-Zone Extraction pumps	15	ea.	$1,828	$27,420
B-Zone Extraction pumps	5	ea.	$2,305	$11,525
Ancillary equipment (PLC, transfer pumps, tanks, etc)	1	LS	$60,000	$60,000
System installation	1	LS	$100,000	$100,000
Air treatment by Activated Carbon	2	ea.	$33,644	$67,288
As-Built Drawings and O&M Manual Preparation	1	LS	$25,000	$25,000
System Startup and Optimization	1	LS	$25,000	$25,000
SUBTOTAL				**$414,100**
Vapor Intrusion Prevention Systems				
Vapor intrusion prevention system installed in homes within the area of observed indoor air impacts, including barrier with under-barrier vapor extraction and treatment (20 homes)	20	homes	$5,000.00	$100,000
SUBTOTAL				**$100,000**
TOTAL DIRECT CAPITAL COSTS				*$1,328,857*
INDIRECT CAPITAL COSTS				
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$199,328	$199,328
Engineering and Construction Oversight (15% Total Direct Costs)	1	LS	$199,328	$199,328
Health and Safety Costs (3% Total Direct Costs)	1	LS	$39,866	$39,866
Project Management & Administration (10% Total Direct Costs)	1	LS	$132,886	$132,886
TOTAL INDIRECT CAPITAL COSTS				**$571,400**
TOTAL CAPITAL COSTS (Direct and Indirect)				*$1,900,257*

O & M COSTS

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Groundwater Treatment System Maintenance (year 1-10)				
System O&M Labor	12	month	$10,000	$120,000
System O&M Subs	1	LS	$30,000	$30,000
System O&M equipment	12	month	$2,250	$27,000
System Sampling and Analysis - VOCs	240	samples	$75	$18,000
System Sampling and Analysis - TDS and Metals	2	samples	$300	$600
Well redevelopment (1/4 of all extraction wells per year)	5	wells	$5,000	$25,000
Supplies	12	month	$2,000	$24,000
Monthly Reporting	12	month	$5,000	$60,000
Annual Reporting	1	LS	$15,000	$15,000
AQMD Reporting (quarterly)	4	qtr	$1,800	$7,200
Discharge Reporting (quarterly)	4.0	qtr	$1,200.00	$4,800
Activated carbon replacement	6100	lb	$1.50	$9,150
Monthly vapor samples	3	samples	$210.00	$630
Discharge Permit	1	LS	$2,415.00	$2,415
Discharge fee	147.2	mil gal	$809.05	$119,066
Electricity	12	month	$4,097	$49,165
SUBTOTAL				**$512,026**
Replacement Costs (7% Total Direct Costs)	1	LS	$35,842	$35,842
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$76,804	$76,804
Health and Safety Costs (3% Total Direct Costs)	1	LS	$15,361	$15,361
Project Management & Administration (10% Total Direct Costs)	1	LS	$51,203	$51,203
SUBTOTAL				**$179,209**
Annual System Maintenance Costs (Year 1-10)				**$691,236**
Groundwater Treatment System Maintenance (year 11-30)				
System O&M Labor	12	month	$10,000	$120,000
System O&M Subs	1	LS	$30,000	$30,000
System O&M equipment	12	month	$2,250	$27,000
System Sampling and Analysis - VOCs	240	samples	$75	$18,000
System Sampling and Analysis - TDS and Metals	2	samples	$300	$600
Well redevelopment (1/4 of all extraction wells per year)	5	wells	$5,000	$25,000
Supplies	12	month	$2,000	$24,000
Monthly Reporting	12	month	$5,000	$60,000
Annual Reporting	1	LS	$15,000	$15,000
AQMD Reporting (quarterly)	4	qtr	$1,800	$7,200
Discharge Reporting (quarterly)	4.0	qtr	$1,200.00	$4,800
Activated carbon replacement	6100	lb	$1.50	$9,150
Monthly vapor samples	3	samples	$210.00	$630
Discharge Permit	1	LS	$2,415.00	$2,415
Discharge fee	147.2	mil gal	$1,471.00	$216,484
Electricity	12	month	$4,097	$49,165
SUBTOTAL				**$609,444**
Replacement Costs (7% Total Direct Costs)	1	LS	$42,661	$42,661
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$91,417	$91,417
Health and Safety Costs (3% Total Direct Costs)	1	LS	$18,283	$18,283
Project Management & Administration (10% Total Direct Costs)	1	LS	$60,944	$60,944
SUBTOTAL				**$213,305**
Annual System Maintenance Costs (Year 10-30)				**$822,750**

DESCRIPTION	QUANTITY		COST	
	Number	Unit	Unit Cost	Total Cost
Ground Water Monitoring Cost Per Event				
Well Sampling Labor and Equipment	60	wells	$213	$12,780
Ground Water Analysis - VOCs (60 wells + 30% QA/QC)	78	samples	$75	$5,850
Ground Water Analysis - MNA Parameters (30 wells)	30	samples	$244	$7,314
Reporting	1	LS	$15,000	$15,000
SUBTOTAL				**$40,944**
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$6,142	$6,142
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,228	$1,228
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,094	$4,094
SUBTOTAL				**$11,464**
Total Costs Per Event				**$52,408**
Annual O&M Cost (Year 1-5, operation and quarterly sampling)				**$900,869**
Annual O&M Cost (Year 6-10, operation and semiannual sampling)				**$796,052**
Annual O&M Cost (Year 11-30, operation and annual sampling)				**$875,158**
SUBTOTAL UNDISCOUNTED O&M COSTS (30 years)				**$25,987,767**
SUBTOTAL NET PRESENT WORTH O&M COSTS (30 years) (1)				**$10,734,035**
Vapor Intrusion Prevention Systems Maintenance				
Air Monitoring (VOC TO-15 samples)	20	samples	$210	$4,200
Electricity (vapor extraction systems, 2 HP fans, Continuous operation)	12	month	$2,831	$33,968
Systems Inspection	20	homes	$350	$7,000
Systems Maintence and Repair	1	LS	$2,500	$2,500
Reporting	1	LS	$5,000	$5,000
SUBTOTAL				**$48,468**
Replacement Costs (7% Total Direct Costs)	1	LS	$3,393	$3,393
Contractor Overhead & Profit (15% Total Direct Costs)	1	LS	$7,270	$7,270
Health and Safety Costs (3% Total Direct Costs)	1	LS	$1,454	$1,454
Project Management & Administration (10% Total Direct Costs)	1	LS	$4,847	$4,847
SUBTOTAL				**$17,000**
Annual O&M Costs (year 1-3)				**$65,468**
SUBTOTAL UNDISCOUNTED O&M COSTS (3 years)				**$196,404**
SUBTOTAL NET PRESENT WORTH O&M COSTS (3 years) (1)				**$171,809**
TOTAL UNDISCOUNTED O&M COSTS				**$26,184,172**
NET PRESENT WORTH OF TOTAL O&M COSTS				**$10,905,844**
TOTAL CAPITAL AND O & M COSTS				*$12,806,101*
General Contingency (0% of Total Capital and O&M Costs)				*$0*
TOTAL COST OF ALTERNATIVE (PRESENT WORTH)				*$12,807,000*

Notes:
(1) Present worth calculated using equal series present worth analysis where i = 7 %